Marine Fisheries REVIEW

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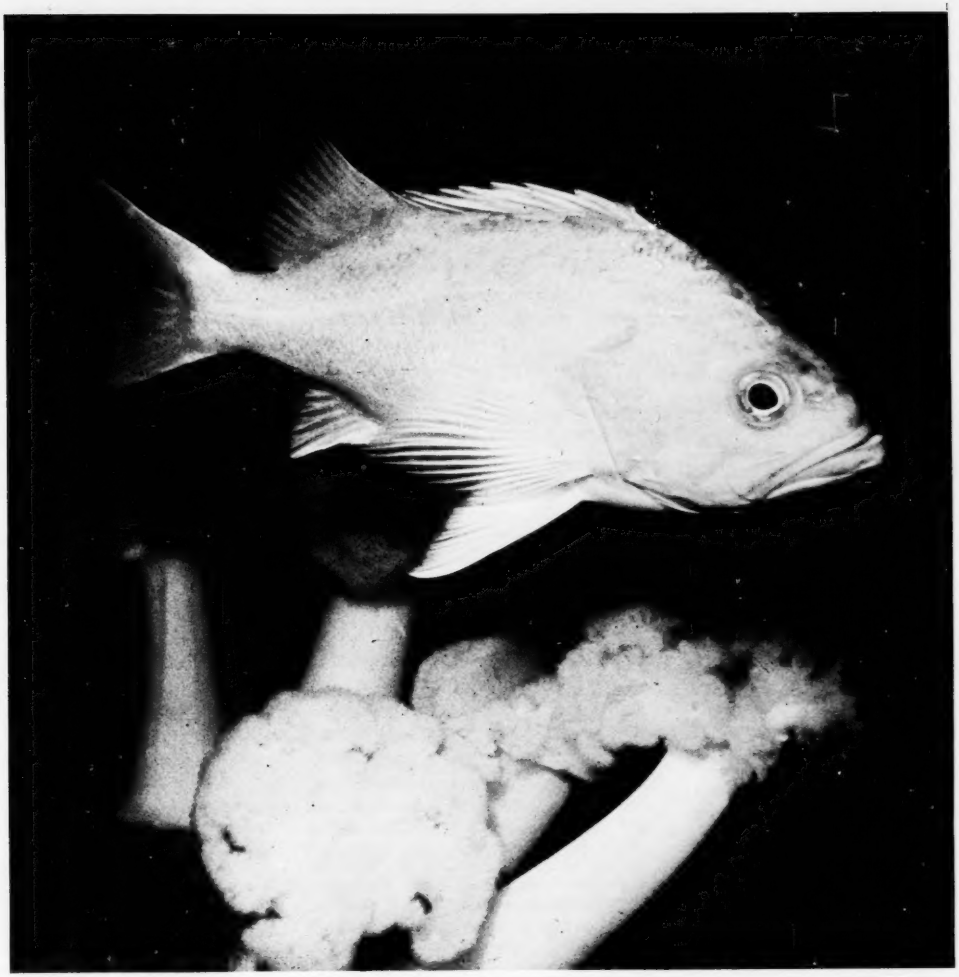

Pacific Coast Rockfish and Whiting

Marine Fisheries REVIEW

On the cover: A canary rockfish, *Sebastes pinniger*, photographed by William L. High, Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd., E., Seattle, WA 98112.

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Cooperative Survey of Rockfish and Whiting Resources Off California, Washington, and Oregon, 1977: Introduction

Papers presented at a symposium in Seattle, Wash., 6-7 July 1978

DONALD R. GUNDERSON and WILLIAM H. LENARZ, Editors

Pacific coast rockfish (genera *Sebastes* and *Sebastolobus*) dominate commercial bottomfish landings in California, Oregon, and Washington. In 1977, 22,900 metric tons (t) of rockfish were landed by commercial fishermen, making up 38 percent of the total bottomfish landings. In addition, at least 2,600 t of rockfish (excluding Puget Sound, Wash., catches) were caught by recreational fishermen during the same year.

The Pacific ocean perch, *Sebastes alutus*, is the most abundant rockfish in the eastern North Pacific Ocean; the species was studied extensively after its rapid and drastic decline due to overexploitation by foreign trawlers in the 1960's. In contrast, only limited research was carried out on rockfish other than Pacific ocean perch, and when the U.S. Fishery Conservation and Management Act of 1976 was enacted, information needed to manage all of the rockfish resource was quite sketchy. Shortcomings in existing knowledge of biology and stock conditions for all rockfish species made it apparent that an intensive survey of these resources would be desirable.

A 3-day workshop was convened in January 1976 at the National Marine Fisheries Service's Northwest and Alaska Fisheries Center (NWAFC), Seattle, Wash., to assess the extent of information on the resource. The workshop was attended by representatives of the California Department of Fish and Game, National Marine Fisheries Service, Oregon Department of Fish and Wildlife, Oregon State University, Washington State Department of Fisheries, and the University of Washington.

A rockfish survey coordinating committee was established at this meeting to develop a cooperative pilot survey in 1976 and a coastwide survey of rockfish and Pacific whiting, *Merluccius productus*, resources in 1977. Meetings between representatives of NMFS and the Polish Sea Fisheries Institute (Gdynia, Poland) in 1977 served to coordinate Polish research efforts with those of the other agencies involved in the rockfish surveys.

Following completion of the 1977 survey, the participants analyzed data on specific areas of interest and responsibility, summarized the results, and prepared reports for a symposium held in July 1978 in Seattle. The papers in this issue, 42(3-4), of *Marine Fisheries Review* were among those presented at the symposium. Results of oceanographic studies carried out during the survey were also presented at the symposium and are available in an article by Ingraham and Love (1978).

The information included in this collection of papers substantially increases our knowledge of Pacific rockfish resources and suggests several important avenues of future research for these species. The magnitude and nature of a latent resource of potential importance (shortbelly rockfish, *Sebastes jordani*) is outlined. Also provided is information on the abundance, age composition, growth, fecundity, and size at maturity for those species that are important commercially: Pacific ocean perch; bocaccio, *Sebastes paucispinis*; chilipepper, *S. goodei*; yellowtail rockfish, *S. flavidus*; and canary rockfish, *S. pinniger*. Patterns in age composition indicated that significant northward migrations of shortbelly rockfish, chilipepper, bocaccio, and yellowtail rockfish occur over the course of their juvenile and adult lives, and a similar phenomenon is suspected in the case of splitnose rockfish, *S. diploproa*, and Pacific ocean perch.

Many rockfish larvae appear to spend several months in the pelagic zone, and this migration is possibly an adaptation to counterbalance the southerly transport that characterizes this region (particularly between Cape Blanco and Point Conception) during much of the year (Bakun et al., 1974). The age composition data together with the results of biochemical genetic studies that were carried out in conjunction with the survey suggest that a much higher degree of intermingling of Pacific coast rockfish stocks takes place than was previously thought to be the case.

Survey results for Pacific whiting were equally useful and supplemented existing knowledge of this important resource considerably. Biomass estimates indicated that the abundance of Pacific whiting increased sharply between 1975 and 1977, due partly to the recruitment of a strong 1973 year class to the stock. This information proved useful in evaluating the status of the Pacific whiting resource and contributed to the decision to increase the Total Allowable Catch for 1979.

The editors are grateful to Roger Pearson, Samuel Waterman, and Rae Mitsuoka of the NWAFC for their assistance in editing the papers in this collection. The assistance of James Peacock and his graphics unit at the laboratory is also gratefully acknowledged.

Literature Cited

Bakun, A., D. R. McLain, and F. Mayo. 1974. The mean annual cycle of coastal upwelling off western North America as observed from surface measurements. Fish. Bull., U.S. 72:843-844.

Ingraham, W. J., Jr., and C. M. Love. 1978. Oceanographic conditions off California to Vancouver Island in the summer of 1977. Mar. Fish. Rev. 40(2):24-28.

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Distribution and Abundance of Rockfish Off Washington, Oregon, and California During 1977

DONALD R. GUNDERSON and TERRANCE M. SAMPLE

Introduction

Soon after the enactment of legislation on extended fisheries jurisdiction, serious shortcomings in the quality of the data base on commercial fisheries for rockfish made it apparent that an intensive survey of rockfish resources would be desirable. The problems to be addressed in implementing such a survey were the subject of discussion at a 3-day workshop held at the Northwest and Alaska Fisheries Center, National Marine Fisheries Service (NMFS), in January 1976 (Gunderson[1]).

As a direct result of that workshop, a pilot survey of rockfish in Monterey Bay, Calif., and Queen Charlotte Sound, British Columbia, was conducted in 1976 to examine and improve the techniques used in rockfish surveys (Gunderson and Nelson[2]). A full-scale survey of rockfish resources from Pt. Hueneme, Calif., (lat. 34°00'N), to Cape Flattery, Wash.,[3] (lat. 48°29'N) was subsequently undertaken in 1977. This survey represented a cooperative effort between NMFS, Washington State Department of Fisheries, Oregon Department of Fish and Wildlife, California Department of Fish and Game, Oregon State University, University of Washington, and Polish Sea Fisheries Institute (Gdynia, Poland).

The survey was subdivided into two major task forces, one carrying out a pelagic (hydroacoustic/midwater trawl) survey, while the other conducted a demersal (bottom trawl) survey. The objectives of the survey were to collect data necessary to: 1) Estimate the demersal biomass for the major species taken in bottom trawl hauls; 2) estimate the biomass of pelagic fish aggregations; 3) determine the species composition of pelagic fish aggregations; 4) determine the size composition of key rockfish species, Pacific whiting, *Merluccius productus*, and sablefish, *Anoplopoma fimbria*, in bottom and midwater trawl catches; 5) determine the age composition in the catches of both types of trawls for selected "target" species (Pacific whiting; chilipepper, *Sebastes goodei*; bocaccio, *S. paucispinis*; shortbelly rockfish, *S. jordani*; splitnose rockfish, *S. diploproa*; yellowtail rockfish, *S. flavidus*; canary rockfish, *S. pinniger*; and Pacific ocean perch, *S. alutus*); 6) determine the acoustic target strength of Pacific whiting and selected rockfish species; 7) characterize oceanographic conditions prevailing in the survey area; 8) determine genetic relationships between rockfish stocks in different areas; 9) determine sizes at maturity and length-fecundity relations for selected rockfish species; and 10) examine the distribution and abundance of cephalopods.

A significant amount of work has proceeded along the lines of the basic objectives since the completion of the 1977 rockfish survey and has been summarized in a series of separate reports. This paper describes the basic methodology used during the demersal survey and summarizes the results of that survey.

Methods

The survey was conducted during 4 July-27 September 1977 and began off Pt. Hueneme, Calif. By beginning in the south, the survey off California coincided as closely as possible to the June-mid-August period when chilipepper and bocaccio were reported to

[1]Gunderson, D. R. 1976. Proceedings of the first rockfish survey workshop, January 20-22, 1976. Unpubl. manuscr., 16 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[2]Gunderson, D. R., and M. O. Nelson. 1977. Preliminary report on an experimental rockfish survey conducted off Monterey, California, and in Queen Charlotte Sound, British Columbia, during August-September 1976. Unpubl. manuscr., 82 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[3]The United States-Canada equidistant line was taken as the northern boundary of the survey area.

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ABSTRACT—The methods employed during the demersal (bottom trawling) phase of the 1977 rockfish survey and in obtaining catch and biological data during the demersal and pelagic (hydroacoustic-midwater) phases are outlined. Geographic and bathymetric trends in the abundance and species composition of the demersal rockfish community are discussed, and the results of the demersal and pelagic surveys are compared. Biomass estimates (50- to 250-fathom or 91- to 457-m depth zone) are given for the dominant rockfish species in each statistical area of the International North Pacific Fisheries Commission (INPFC).

Canary rockfish, Sebastes pinniger *(26,000 t), yellowtail rockfish,* S. flavidus *(23,000 t), and Pacific ocean perch,* S. alutus *(15,000 t), dominated the rockfish biomass in the Vancouver and Columbia INPFC areas. Rockfish biomass was low in the Eureka area (about 4,000 t in the 50- to 250-fathom zone) but increased again to the south. The rockfish biomass in the Monterey and Conception INPFC areas was dominated by shortbelly rockfish,* S. jordani *(320,000 t), splitnose rockfish,* S. diploproa *(10,000 t), chilipepper,* S. goodei *(9,000 t), stripetail rockfish,* S. saxicola *(7,000 t), and bocaccio,* S. paucispinis *(6,000 t). Shortbelly rockfish were found to be principally pelagic in their distribution; less than 10 percent of the stock was encountered during the demersal survey.*

The precision of most biomass estimates for rockfish was relatively low because of the highly contagious spatial distribution characterizing most of these species.

be most available to commercial trawlers in that area. The survey off Washington and northern Oregon took place during late August-late September, a period when the availability of Pacific ocean perch to bottom trawls is at a peak (Gunderson, 1977).

The survey area was subdivided into 14 geographic strata (Fig. 1) on the basis of historical fisheries patterns. Each of these was further subdivided into four depth strata (50-99, 100-149, 150-199, and 200-250 fathoms or 91-181, 183-272, 274-364, and 366-457 m) since it was known that rockfish abundance, species composition, and size composition all vary with depth. Those areas that were known to produce high catches of rockfish were singled out for intensive, high density sampling (designated by an H in Figure 1). Four untrawable areas (36°00′ - 36°16′ N, 36°30′ - 36°38′ N, 36°46′ - 36°51′ N, and 40°16′ - 40°25′ N) were delineated, and no attempt was made to trawl in those areas or to estimate the biomass of demersal stocks inhabiting them. Thirteen biological sampling strata were designated (Fig. 1) so that the distribution and intensity of sampling of otoliths, tissues for genetic studies, and ovaries for fecundity studies could be specified.

On the basis of an analysis of alternative survey design strategies using data from the 1976 pilot survey (Lenarz[4]), a systematic series of tracklines were selected every 5 nautical miles (9.3 km) in strata selected for high-density sampling and every 10 nautical miles (18.5 km) in other strata. This was done by choosing a single starting point at Cape Flattery, then proceeding south along the 50-fm (91-m) contour at the appropriate intervals. All tracklines were drawn perpendicular to the 50-fm (91-m) contour.

Supplementary tracklines were added in Juan de Fuca and Astoria canyons where the isobaths turned perpendicular to the coast. These were chosen at 5-nautical-mile (9.3-km) intervals, beginning at the point where the deepest contour turned perpendicular to the coast, and ran between 100-fathom (183-m) contours.

Along each trackline, the number of stations to be sampled in each of the four depth strata was chosen by the following rule:

Linear distance along trackline (nautical miles; km)	No. of stations
<5; 9.3	1
5- 9; 9.3-16.7	2
10-14; 18.5-25.9	3
15-19; 27.8-35.2	4
etc.	

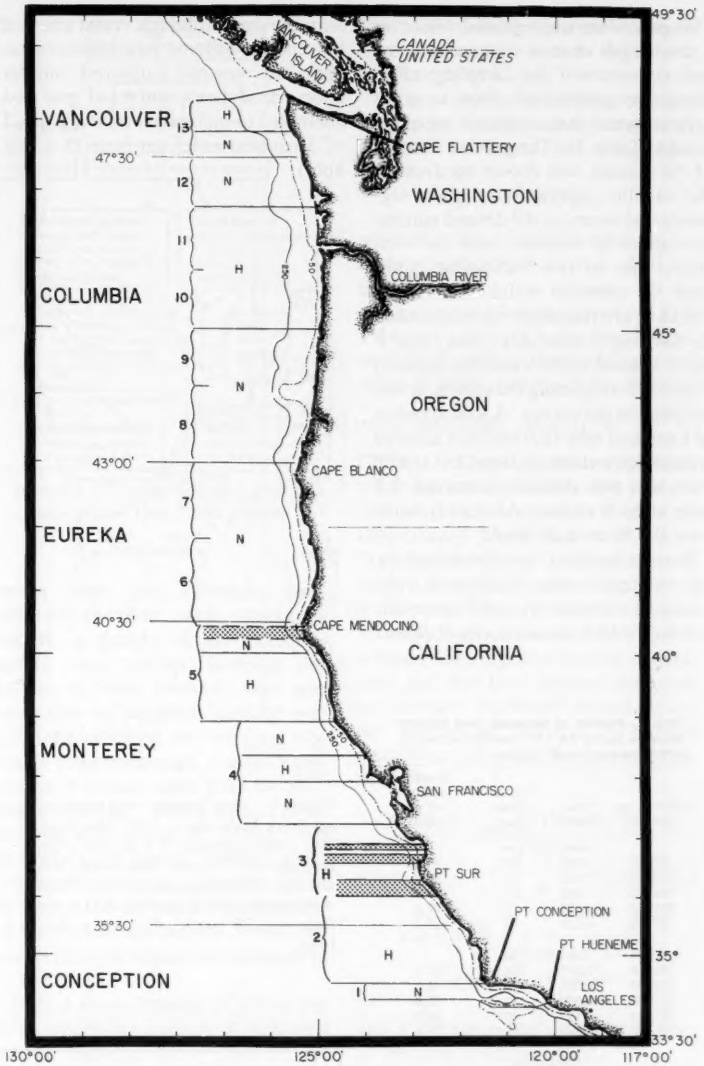

Figure 1.—Geographic sampling strata for the 1977 rockfish survey, N = normal trackline density (10 nautical miles or 18.5 km spacing), H = high trackline density (5 nautical miles or 9.3 km spacing). Stippling denotes untrawlable bottom. Biological sampling strata are indicated by the brackets.

[4]Lenarz, W. H. 1977. Comparison of random, stratified random, and systematic sampling for rockfish. Unpubl. manuscr., 19 p. Southwest Fisheries Center, NMFS, NOAA, 3150 Paradise Drive, Tiburon, CA 94920.

This procedure was repeated whenever a new depth stratum was encountered and concentrated the sampling effort along the continental slope to a far greater extent than a random sampling design (Table 1). The precise location of the stations was chosen by dividing the trackline section into n equal segments and choosing the desired number of stations at random, with the constraint that no two stations be closer than 2 nautical miles (3.7 km). Rockfish are frequently most abundant in marginally trawlable areas, and if there seemed to be even the slightest chance of completing the station, it was included in the survey. A search radius of 1 nautical mile (1.9 km) was allowed around untrawlable stations, but search time was not allowed to exceed 0.5 hour at each station. All survey hauls were 0.5 hour in duration.

Bottom trawling was conducted by the chartered stern trawlers *Pacific Raider, Tordenskjold*, and *Commando* and the NOAA research vessel *David Starr Jordan*. Although vessel size and horsepower differed (see following table), all vessels employed similar doors, dandylines, and trawl gear and attempted to maintain a trawling speed of 3 nautical miles per hour (5.6 km/hour).

Vessel	Overall length (ft; m)	Continuous horsepower
Pacific Raider	125; 38.1	750
Tordenskjold	75; 22.9	350
Commando	67; 20.4	365
Jordan	171; 52.1	918

Table 1.—Number of demersal trawl stations occupied during the 1977 rockfish survey by INPFC[1] area and depth stratum.

Depth range (fathoms)	Area (km²)	No. of usable hauls	Sampling density (km² per station)
	Vancouver Area		
50- 99	2,843	32	88.8
100-149	803	17	47.2
150-199	385	14	27.5
200-250	193	7	27.6
50-250	4,224	70	60.3
	Columbia Area		
50- 99	10,547	104	101.4
100-149	2,322	51	45.5
150-199	1,680	33	50.9
200-250	2,193	40	54.8
50-250	16,742	228	73.4
	Eureka Area		
50- 99	2,451	20	122.6
100-149	600	14	42.9
150-199	494	13	38.0
200-250	488	12	40.7
50-250	4,033	59	68.4
	Monterey Area		
50- 99	5,396	78	69.2
100-149	978	43	22.7
150-199	818	44	18.6
200-250	817	41	19.9
50-250	8,009	206	38.9
	Conception Area		
50- 99	1,486	28	53.1
100-149	1,213	29	41.8
150-199	872	19	45.9
200-250	1,159	25	46.4
50-250	4,730	101	46.8

[1] International North Pacific Fisheries Commission.

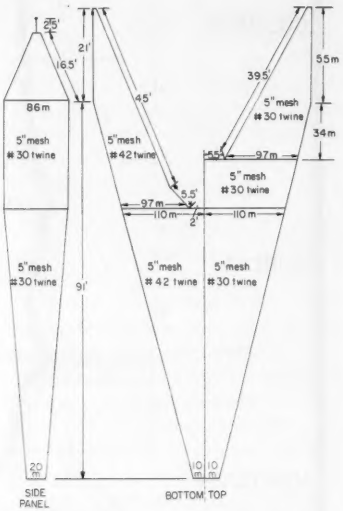

Figure 2.—Nor'Eastern otter trawl (m = meshes). Footrope = 105'; headrope = 90'; circumference = 632 m/5"; intermediate = 3.5"mesh, #60 twine, 105 m around, 60 m long; codend = 3.5"mesh, #96 twine, 105 m around, 120 m long; liner = 1.25" mesh, #18 twine, 300 m long.

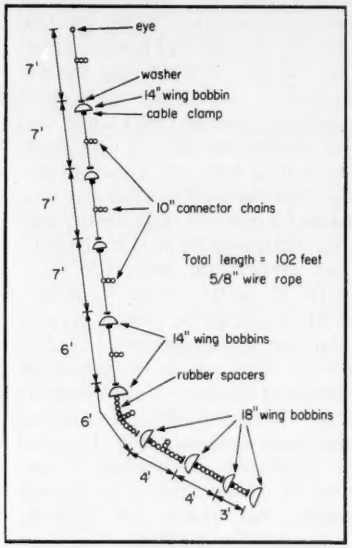

Figure 3.—One-half string of roller gear used for the Nor'Eastern otter trawl.

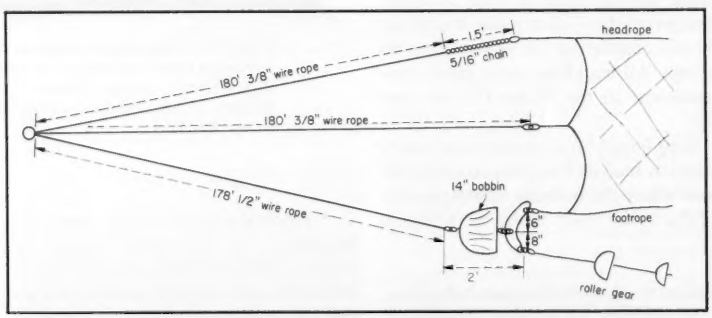

Figure 4.—Dandyline and wing-tip bobbin configuration used on the Nor'Eastern otter trawl.

There were small differences in the weight of the trawl doors employed by the four vessels (1,000-1,250 pounds or 454-567 kg) and in the length of the tail chains/sweeplines used to attach the doors to the dandylines (8-18 feet or 2.4-5.5 m), but other differences were minor. All four vessels employed a Nor'Eastern[5] otter trawl (Fig. 2) with the roller gear and dandyline configuration shown in Figures 3 and 4. Measurements of the operating characteristics of the Nor'Eastern trawl were obtained by using an acoustic measuring device (Wathne, 1977) and indicated that the Nor'Eastern trawl has a horizontal sweep (wing tip to wing tip) of 44 feet (13.4 m) and a vertical opening (at the center of the headrope) of 29 feet (8.8 m) when rigged and towed as it was during the survey.

Processing of a typical trawl catch obtained during the survey is outlined in Figure 5. All catches less than about 2,500 pounds (1,134 kg) were dumped directly from the cod end into a sorting table, then sorted into baskets by species. Up to nine of these baskets were then weighed to the nearest 0.5 pound (0.2 kg) on a platform scale and the total weight caught extrapolated from them. Catches larger than the 2,500-pound sorting table capacity were subsampled using the cargo net system described in Hughes (1976), then processed in a similar fashion.

Once the catch (or the sample of the catch) had been sorted by species, biological samples were obtained to determine the size composition of all "target" species (Pacific whiting; sablefish; bocaccio; chilipepper; shortbelly rockfish; splitnose rockfish; canary rockfish; yellowtail rockfish; darkblotched rockfish, *S. crameri*; silvergray rockfish, *S. brevispinis*; and Pacific ocean perch) by sex. Each biological sample was obtained by taking an equal proportion from the first, middle, and last row of baskets sorted (after Westrheim, 1967) and usually consisted of up to 200 fish. For all

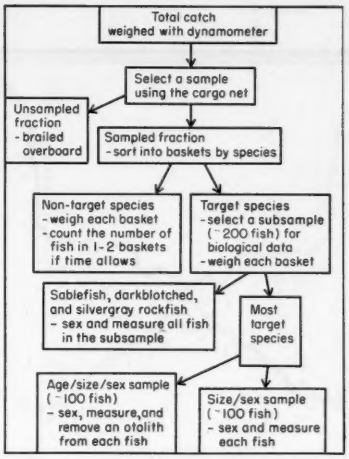
Total catch weighed with dynamometer
Select a sample using the cargo net
Unsampled fraction - brailed overboard
Sampled fraction - sort into baskets by species
Non-target species - weigh each basket - count the number of fish in 1-2 baskets if time allows
Target species - select a subsample (~200 fish) for biological data - weigh each basket
Sablefish, darkblotched, and silvergray rockfish - sex and measure all fish in the subsample
Most target species
Age/size/sex sample (~100 fish) - sex, measure, and remove an otolith from each fish
Size/sex sample (~100 fish) - sex and measure each fish

Figure 5.—Typical processing of a catch greater than 2,500 pounds.

species other than sablefish, darkblotched rockfish, and silvergray rockfish, a portion of the biological sample was further sampled for otoliths, as time allowed. This was done either by randomly picking one-half of the baskets in the biological subsample (making certain that an equal number of baskets came from the first, middle, and last portions sorted) or by removing a fixed number of fish from the top of each basket. Otolith collections were usually geared to the size of the catch, with the objective of collecting the bulk of the otoliths for a given species from the largest catches made in the area.

Only a minor amount of effort was spent processing catches of nontarget species, although the number of fish caught was determined for small catches. Mean weight was determined for larger catches as time allowed by counting the number of fish in one or two baskets, then weighing them. The mean weight data were then used to estimate the total number of fish caught for that species.

Estimates of the number caught were almost always obtained for the target species, either by direct count or by extrapolating the mean weight of individuals in the length-frequency sample to the entire catch. Length-frequency data were usually obtained for each target species if 10 or more individuals were caught in a haul.

Biomass estimates for the predominant species in each survey area were obtained by depth and geographic stratum from:

$$\hat{B}_i = \frac{A_i}{a}\ \overline{\text{CPUE}}_i$$

where $\hat{B}_i$ is the estimated biomass in the ith geographic/depth stratum, A_i is the total area within that stratum, a is the area swept per kilometer by a trawl with a 44-foot (13.4-m) horizontal spread, and $\overline{\text{CPUE}}_i$ is the average catch per unit effort (CPUE, kg/km) in the stratum, based on n_i hauls $\left(\overline{\text{CPUE}}_i = \frac{1}{n_i}\sum_{j=1}^{n_i} \text{CPUE}_{ij}\right)$. These biomass estimates were then summed across all h strata to obtain a biomass estimate $\hat{B}$ for each International North Pacific Fisheries Commission (INPFC) statistical area (Fig. 1) along the Pacific coast. On the assumption that the survey stations within each stratum were randomly distributed with respect to the fish populations and that total biomass estimates are normally distributed around the actual biomass for that area, 90 percent confidence limits for $\hat{B}$ were approximated by:

$$\hat{B} \pm t_{(.90,n_e)}\ (\text{Var}\,\hat{B})^{1/2}$$

where $\text{Var}\,\hat{B} = \sum_{i=1}^{h}\left(\frac{A_i}{a}\right)^2 \text{Var}\,(\overline{\text{CPUE}}_i)$,

$$\text{Var}\,(\overline{\text{CPUE}}_i) = \frac{1}{n_i(n_i-1)}\sum_{j=1}^{n_i}(\text{CPUE}_{ij}-\overline{\text{CPUE}}_i)^2$$

and n_e = number of effective degrees of freedom (Cochran, 1962).

Results

The relative abundance (kilograms caught per kilometer trawled) of the dominant rockfish species encountered during the demersal survey is shown geographically in Figures 6-14, and by INPFC area and depth in Table 2.

Three distinct regions can be used to describe the patterns of demersal rockfish distribution observed during the 1977 survey. The most northern region extended from Cape Flattery to Cape Blanco (Vancouver and Colum-

[5]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

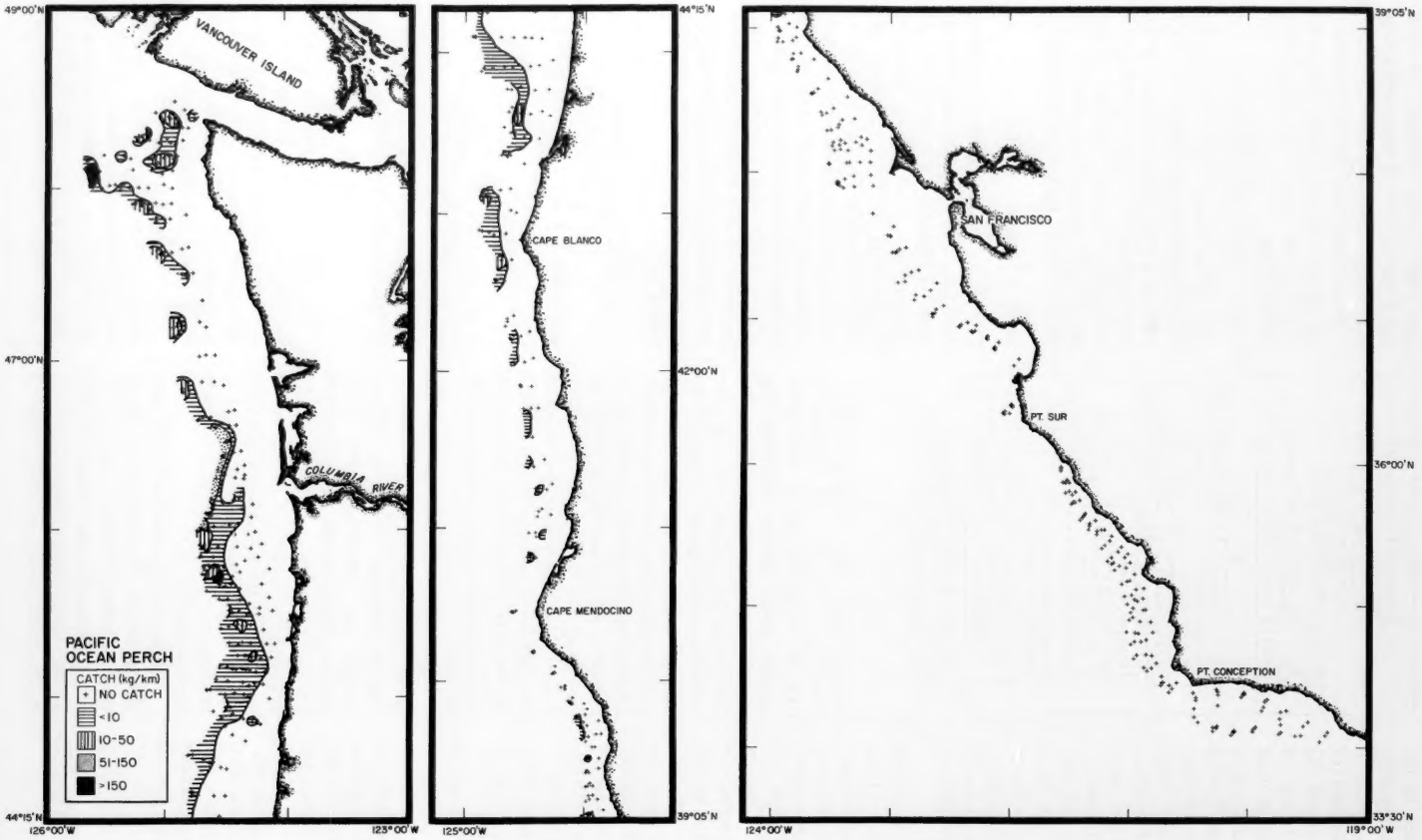

Figure 6.—Distribution and relative abundance of Pacific ocean perch off Washington, Oregon, and California, 1977.

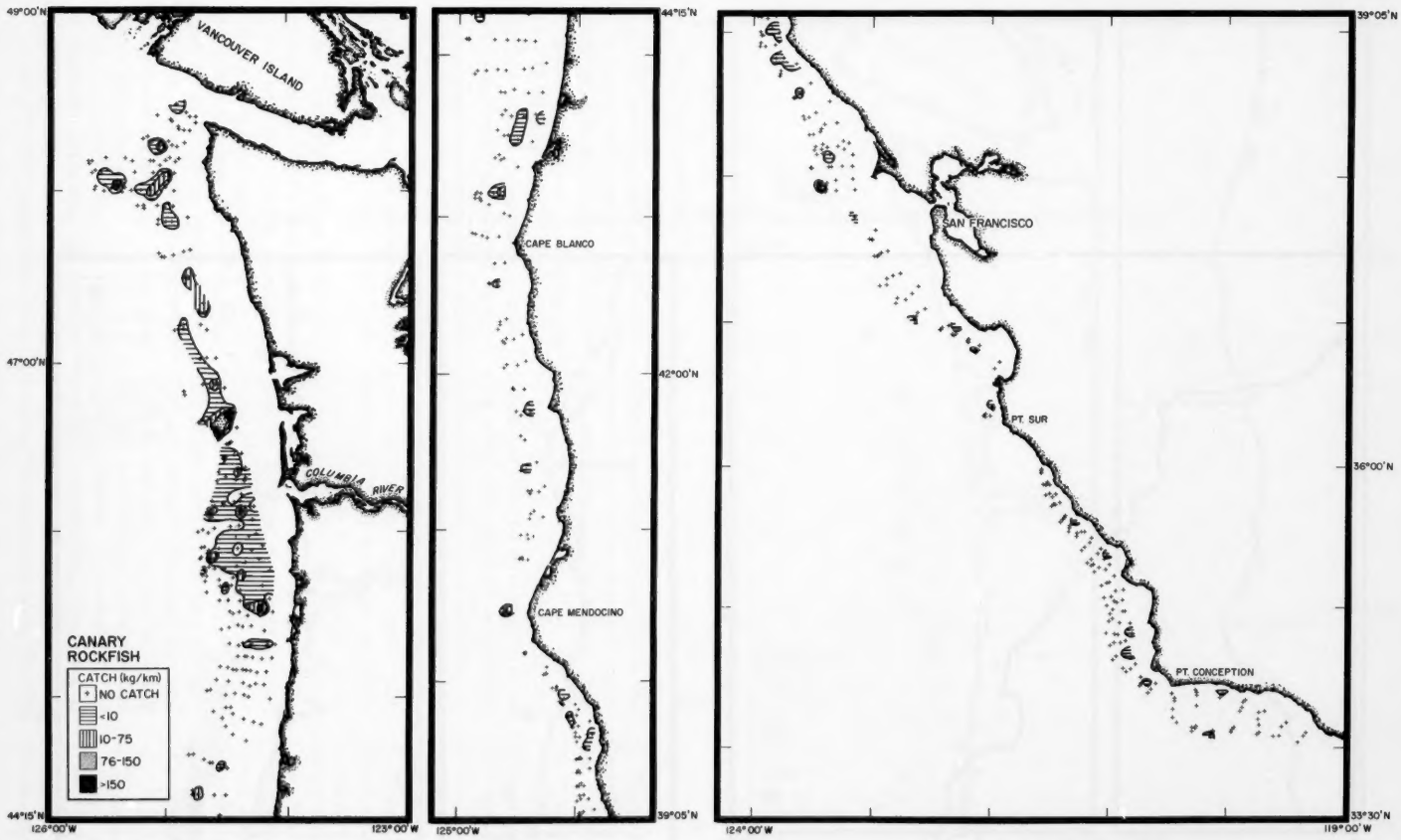

Figure 7.—Distribution and relative abundance of canary rockfish off Washington, Oregon, and California, 1977.

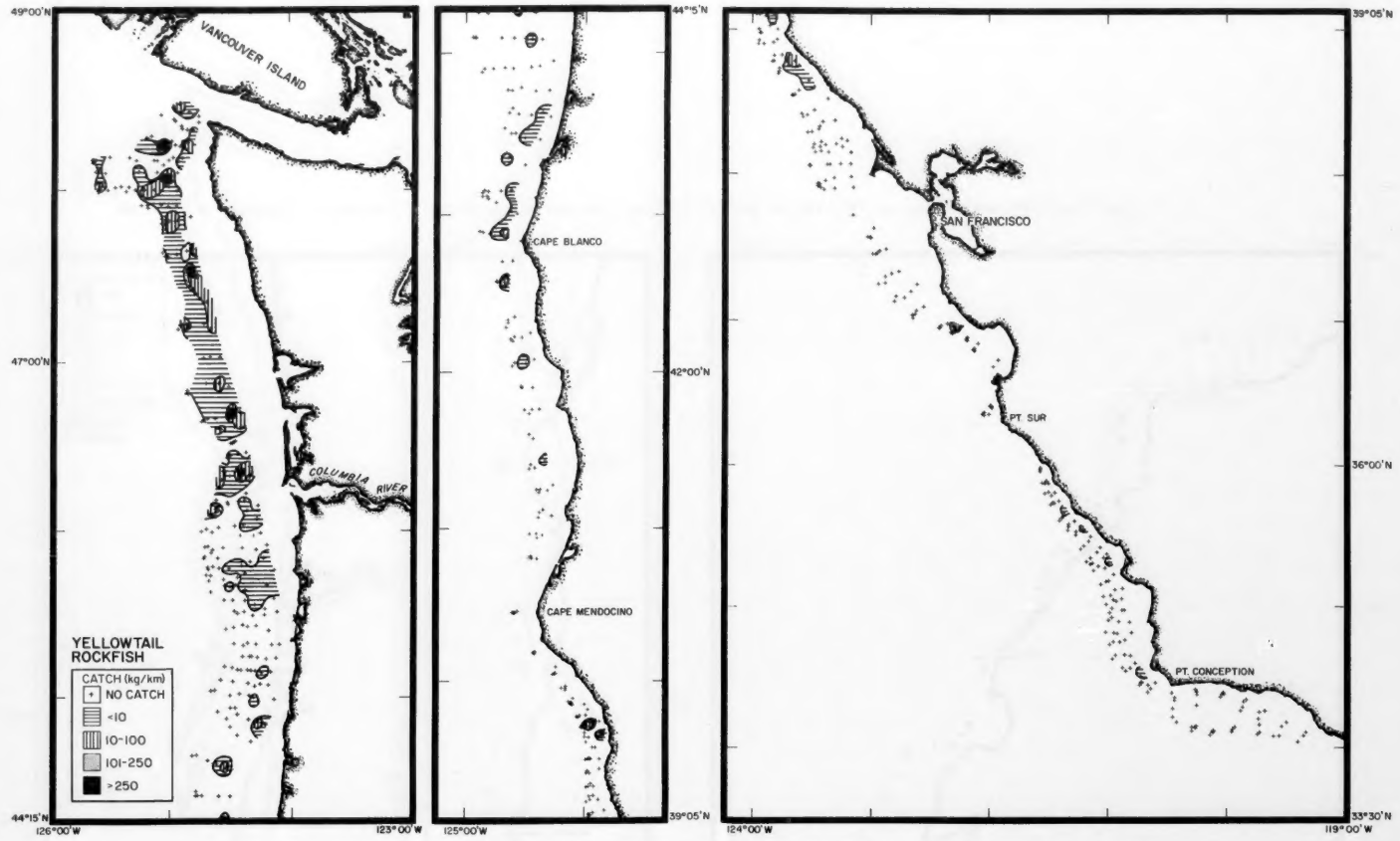

Figure 8.—Distribution and relative abundance of yellowtail rockfish off Washington, Oregon, and California, 1977.

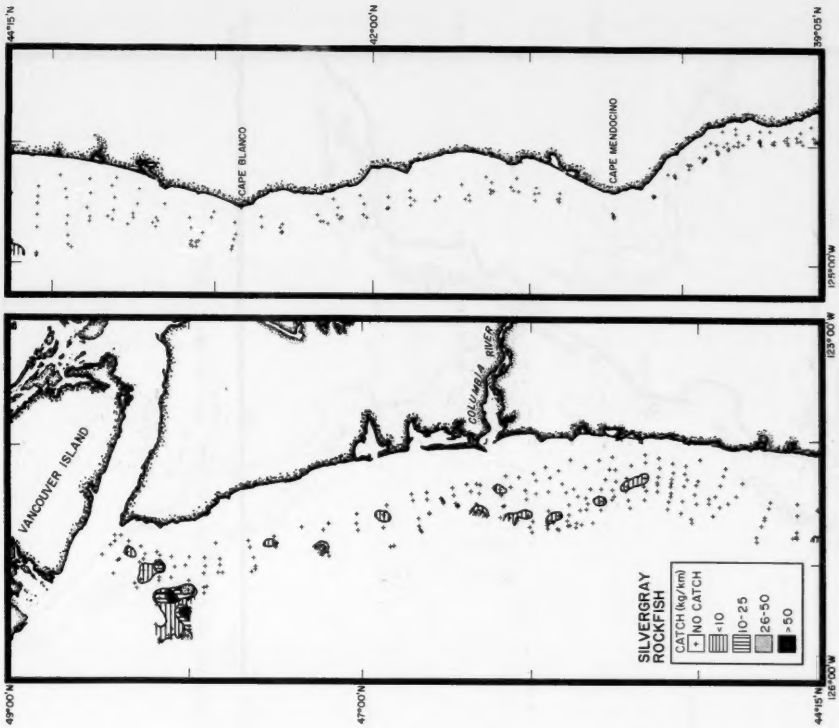

Figure 9.—Distribution and relative abundance of silvergray rockfish off Washington, Oregon, and California, 1977.

bia INPFC areas) and was characterized by a canary-yellowtail-silvergray assemblage in 50-99 fathoms (91-181 m), a Pacific ocean perch assemblage in 100-199 fathoms (183-364 m), and a Pacific ocean perch-rougheye, *S. aleutianus*-shortspine thornyhead, *Sebastolobus alascanus*, assemblage in 200-260 fathoms (366-475 m). Silvergray rockfish were confined to the most northerly portions of the survey area, and were most abundant in the Vancouver area.

The Cape Blanco-Cape Mendocino region (Eureka INPFC area) was a region of very low rockfish abundance. Yellowtail and stripetail, *S. saxicola*, rockfish dominated the rockfish assemblage in the 50- to 99-fathom (91- to 181-m) zone, while darkblotched and splitnose rockfish dominated from 100 to 260 fathoms.

The third region, Cape Mendocino to Pt. Hueneme (Monterey and Conception INPFC areas) was characterized by a shortbelly-chilipepper-bocaccio-stripetail assemblage in the 50- to 99-fathom (91- to 181-m) zone and a splitnose assemblage in the 200- to 260-fathom (366- to 475-m) zone. The intermediate depth zone (100-199 fathoms or 183-364 m) seemed to be an area where the splitnose assemblage gradually replaced the assemblage inhabiting the continental shelf. The abundance of rockfish varied substantially within this region, with catch rates being much higher in the Monterey INPFC area than they were to the south (Table 2).

Although shortbelly rockfish dominated the demersal biomass of rockfish in the Monterey area, results from the hydroacoustic survey indicate that the bulk of this stock is found in midwater. The area between Monterey Bay and San Francisco Bay (Fig. 12) was clearly indicated as the area containing the most significant concentrations of shortbelly rockfish during the demersal and pelagic surveys, but the estimated midwater biomass in this area (295,000 t) (Northwest and Alaska Fisheries Center[6]) was over 10 times greater than the demersal biomass for the entire Monterey area (Table 3).

Biomass estimates for the dominant rockfish species encountered during the 1977 survey are shown in Table 3. In addition to the species mentioned previously, several additional species made up a major portion of the biomass in certain areas. Widow rockfish, *Sebastes entomelas*, redstripe rockfish, *S. proriger*, and bocaccio made up a significant portion of the biomass in the Cape Flattery-Cape Blanco region (Vancouver and Columbia INPFC areas), and were most abundant in the 50- to 99-fathom (91- to 181-m) zone. Darkblotched and sharpchin rockfish, *S. zacentrus*, contributed significantly

[6]Northwest and Alaska Fisheries Center. 1978. Cruise results, NOAA R/V *Miller Freeman*, Cruise No. MF-77-02, July 12-September 30, 1977. Unpubl. rep., 19 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

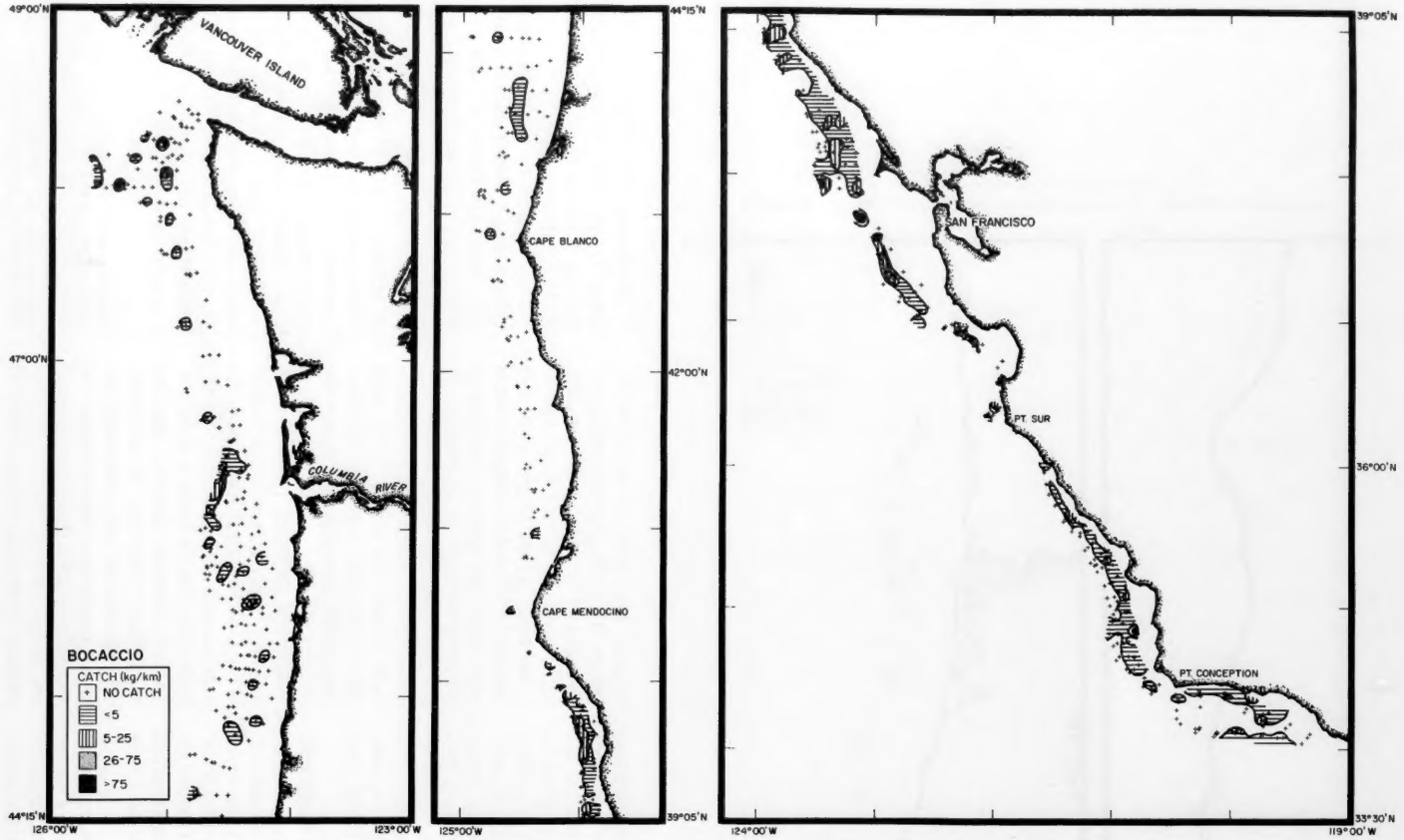

Figure 10.—Distribution and relative abundance of bocaccio off Washington, Oregon, and California, 1977.

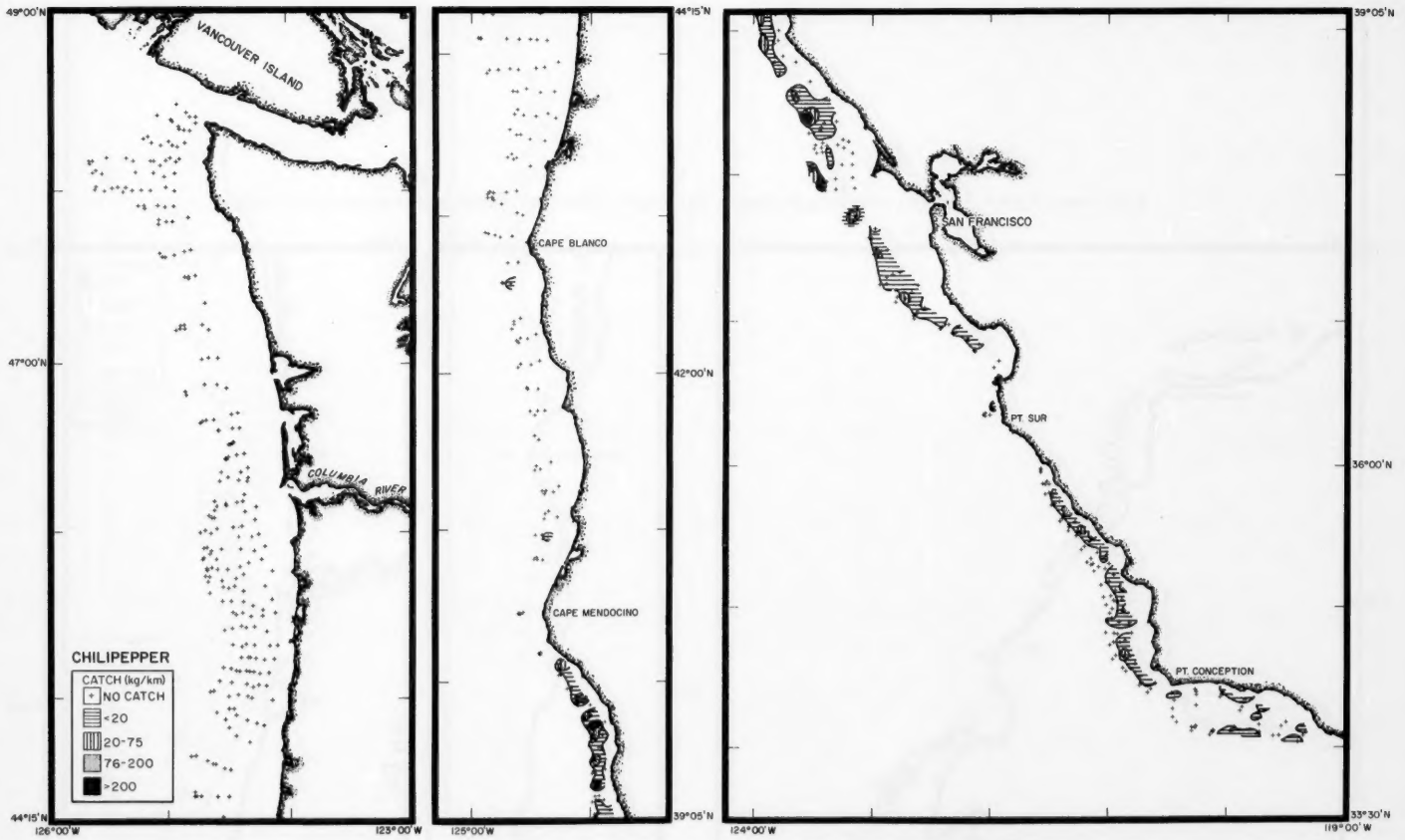

Figure 11.—Distribution and relative abundance of chilipepper off Washington, Oregon, and California, 1977.

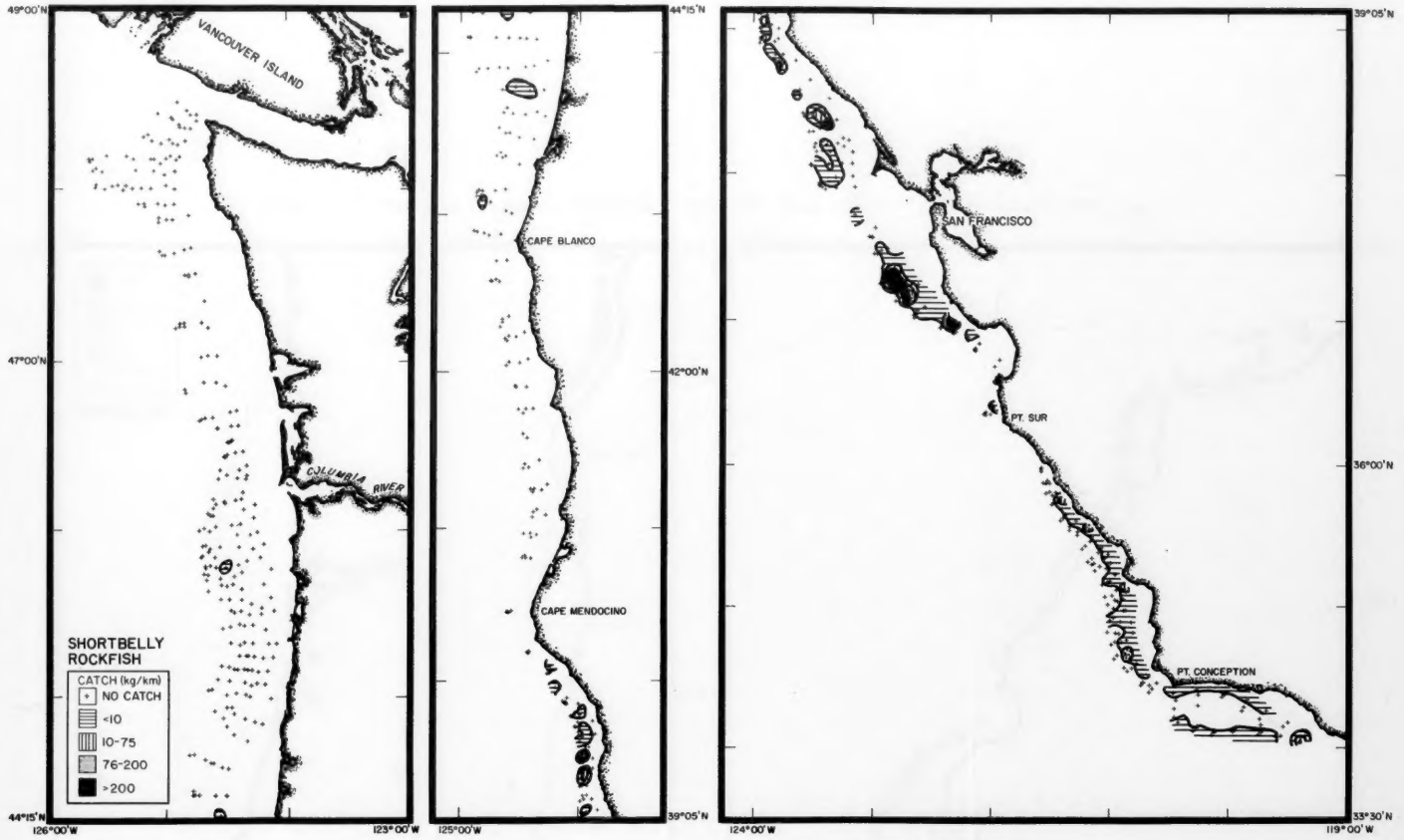

Figure 12.—Distribution and relative abundance of shortbelly rockfish off Washington, Oregon, and California, 1977.

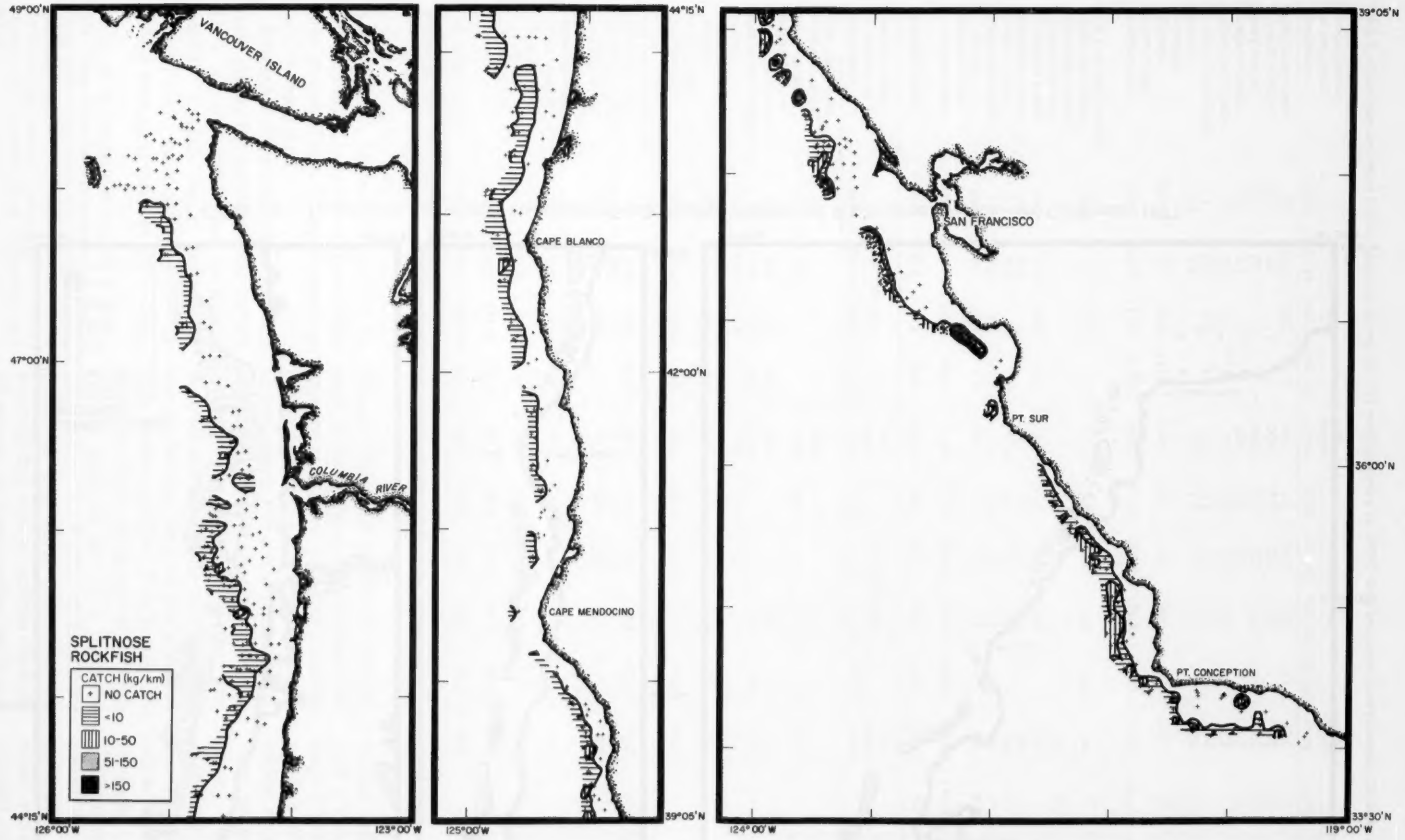

Figure 13.—Distribution and relative abundance of splitnose rockfish off Washington, Oregon, and California, 1977.

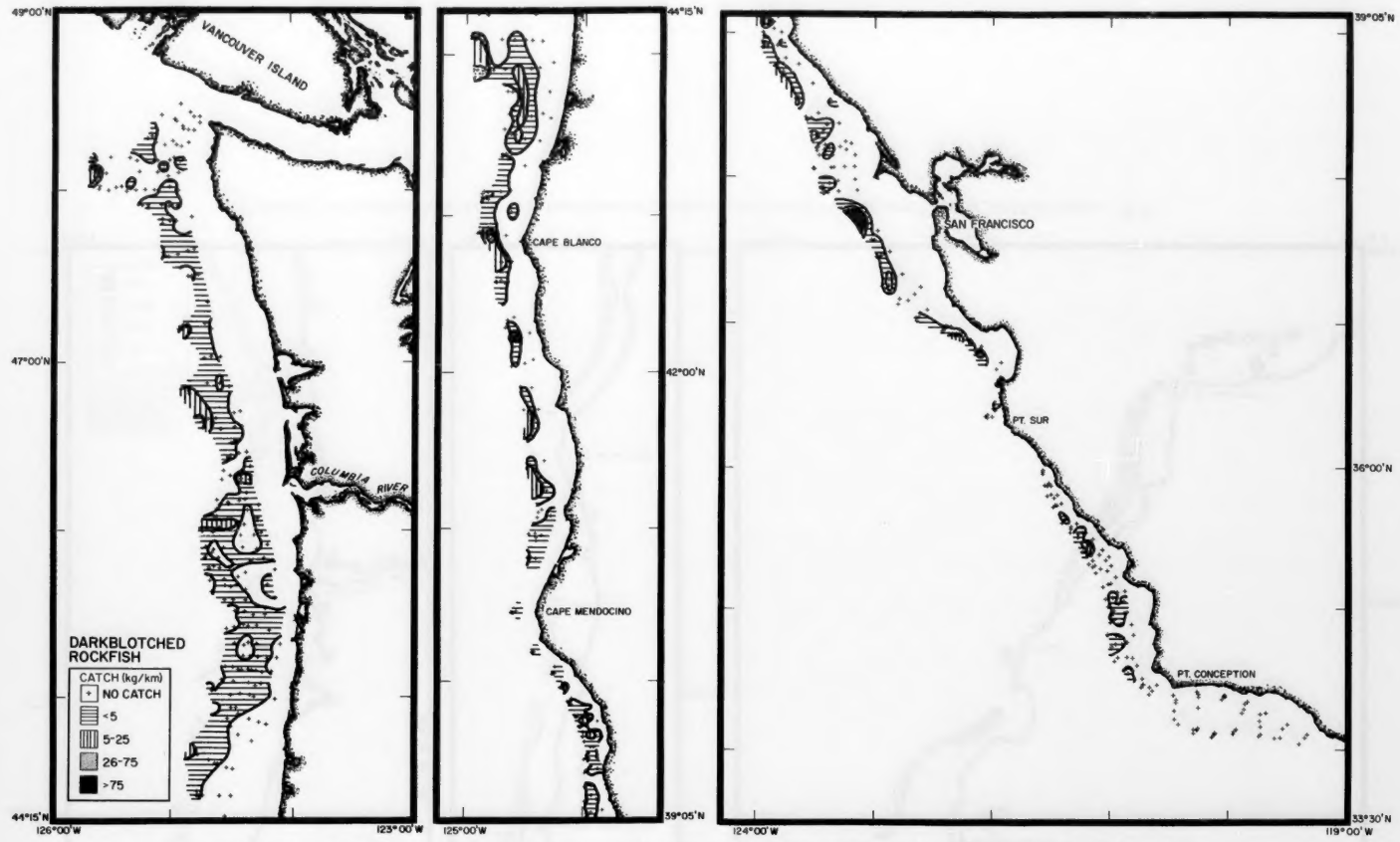

Figure 14.—Distribution and relative abundance of darkblotched rockfish off Washington, Oregon, and California, 1977.

Table 2.—Catch per unit effort (kg/km) obtained during the 1977 rockfish survey by INPFC[1] area and depth zone (fathoms). Quantities less than 0.1 kg/km are not shown.

Principal species of commercial importance	Vancouver Area				All depths comb.	Columbia Area				All depths comb.	Eureka Area				All depths comb.
	50-99	100-149	150-199	200-260		50-99	100-149	150-199	200-260		50-99	100-149	150-199	200-260	
Pacific ocean perch	0.9	101.2	45.0	9.0	35.4	1.5	26.5	16.6	3.1	9.6	0.1	3.2	2.2	0.1	1.3
Yellowtail rockfish[2]	58.2	3.0			26.9	15.4	2.2	0.2		7.5	3.6	0.3			1.3
Canary rockfish	104.1	0.1			46.8	9.9	2.8	0.2		5.2	0.2				0.1
Silvergray rockfish	71.4	7.2			33.9	0.1	2.1			0.5					
Darkblotched rockfish	0.2	0.3	3.7	0.8	1.0	1.0	4.5	3.4	1.3	2.2		7.4	4.1	0.9	2.8
Shortspine thornyhead		2.0	3.3	3.8	1.5	0.9	2.7	5.5	3.0	2.3		1.5	0.4	0.3	0.5
Bocaccio	8.2	0.8			3.9	0.9	1.9	0.1		0.9	0.1	0.2			0.1
Chilipepper											0.6				0.2
Subtotal	243.0	114.6	52.0	13.6	149.4	29.7	42.7	26.0	7.4	28.2	4.6	12.6	6.7	1.3	6.3
Percent of total rockfish catch	(89.5)	(86.3)	(67.4)	(51.1)	(86.4)	(76.2)	(69.8)	(72.2)	(56.5)	(72.5)	(54.8)	(76.8)	(35.8)	(48.1)	(55.3)
Other prominent rockfish															
Splitnose rockfish	0.2	1.1	19.0		4.2	0.1	3.1	3.8	0.6	1.4		2.5	11.0	0.3	3.1
Shortbelly rockfish[2]															
Stripetail rockfish						0.2	0.5			0.2	3.6	0.6			1.4
Sharpchin rockfish	1.1	5.9	0.2		2.0	1.1	10.0	1.2		2.9					
Redstripe rockfish	9.9	2.6			5.1	5.3	1.0			2.6					
Widow rockfish[2]	15.2	2.8			7.5	0.2	0.8	0.3		0.3	0.1	0.1			0.1
Rougheye rockfish	0.1	0.9	3.1	7.5	1.6	0.2	0.2	1.7	3.5	1.0			0.2		
Subtotal	26.5	13.3	22.3	7.5	20.4	7.1	15.6	7.0	4.1	8.4	3.7	3.2	11.2	0.3	4.6
Percent of total rockfish catch	(9.8)	(10.0)	(28.9)	(28.2)	(11.8)	(18.2)	(25.5)	(19.4)	(31.3)	(21.6)	(44.0)	(19.5)	(59.9)	(11.1)	(40.4)
All rockfish comb.	271.6	132.8	77.2	26.6	172.9	39.0	61.2	36.0	13.1	38.9	8.4	16.4	18.7	2.7	11.4

Principal species of commercial importance	Monterey Area				All depths comb.	Conception Area				All depths comb.
	50-99	100-149	150-199	200-260		50-99	100-149	150-199	200-260	
Pacific ocean perch										
Yellowtail rockfish	2.2				0.8					
Canary rockfish	1.0	1.0			0.6	0.3				0.1
Silvergray rockfish										
Darkblotched rockfish	1.3	4.5	6.5	0.8	3.0			0.6		0.1
Shortspine thornyhead		0.5	1.5	1.1	0.6		0.1	0.3	0.6	0.3
Bocaccio	5.5	26.0	0.6		7.6	5.9	2.3			2.3
Chilipepper	13.1	38.9	7.8		14.8	0.6	1.5			0.6
Subtotal	23.1	70.9	16.4	1.9	27.4	6.8	3.9	0.9	0.6	3.4
Percent of total rockfish catch	(28.3)	(45.2)	(19.9)	(6.6)	(31.5)	(28.0)	(12.6)	(3.4)	(4.2)	(14.2)
Other prominent rockfish										
Splitnose rockfish		21.0	58.6	20.7	21.0	0.1	13.7	24.0	11.0	11.2
Shortbelly rockfish[2]	51.8	26.9	1.1		25.2	3.1	3.0			1.7
Stripetail rockfish	5.3	33.4	1.3	0.1	9.3	12.4	9.5			6.2
Sharpchin rockfish		0.4			0.1					
Redstripe rockfish										
Widow rockfish	0.2	0.9	0.1		0.3	1.0	0.1			0.3
Rougheye rockfish				0.1					0.2	
Subtotal	57.3	82.6	61.1	20.9	55.9	16.6	26.3	24.0	11.2	19.4
Percent of total rockfish catch	(70.1)	(52.6)	(74.1)	(73.1)	(64.3)	(68.3)	(85.1)	(91.6)	(78.3)	(80.8)
All rockfish comb.	81.7	156.9	82.5	28.6	86.9	24.3	30.9	26.2	14.3	24.0

[1]International North Pacific Fisheries Commission.
[2]Significant quantities of this species were found in midwater.

to the rockfish biomass in the 100- to 200-fathom (183- to 366-m) zone in the same region (Table 2), particularly in the Columbia area.

Judging from midwater trawl catches made during the hydroacoustic survey (Dark et al., 1980) and incidental rockfish catches made during the Soviet-Polish midwater fishery for Pacific whiting (French et al.[7]), a significant portion of the widow rockfish stock in the Vancouver-Columbia area appears to exist in midwater, and the biomass estimates in Table 3 probably underestimate the actual biomass substantially. Some midwater concentrations of yellowtail rockfish were also encountered during the hydroacoustic survey, but they were far less abundant than widow rockfish. This is substantiated by data on incidental rockfish catches made in the 1977 midwater trawl fishery for Pacific whiting in the Columbia area, since U.S. observers reported that widow rockfish made up 69 percent of these catches while yellowtail rockfish made up only 2 percent (French et al., footnote 7). No large (>225 kg) midwater catches of rockfish other than shortbelly rockfish, widow rockfish, or yellowtail rockfish were made during the hydroacoustic survey (Dark et al., 1980), and shortbelly rockfish was the only species that was plentiful enough to allow estimates of pelagic biomass to be made.

Shortspine thornyheads are known to extend out to about 500 fathoms (914 m) (Alton, 1972) in significant quantities, and the region surveyed in 1977 covered only the shallowest portions of

[7]French, R., R. Nelson, J. Wall, and D. Hennick. 1978. Data from the observations of foreign fishing fleets off the coast of California, Oregon and Washington, 1977. Unpubl. manuscr., 21 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

their bathymetric range. The biomass estimates in Table 3 substantially underestimate their total biomass as a result. Catch rates for the 50- to 250-fathom (91- to 457-m) survey area were highest in the Cape Flattery-Cape Blanco region, although the largest commercial landings of this species (Fraidenburg et al., 1977) occur in the Eureka area.

Table 3.—Estimated demersal biomass ($\hat{B}$) of key rockfish species in the 50- to 250-fathom (91- to 457-m) depth zone, as determined from 1977 rockfish survey data.

INPFC[1] area and species	$\hat{B}$ (t)	90% Confidence limits Lower	Upper
S. Vancouver[2]			
Pacific ocean perch	7,730	0	16,370
Canary	19,940	0	53,350
Yellowtail	11,480	140	22,820
Silvergray	3,100	0	7,860
Bocaccio	1,620	0	4,080
Darkblotched	190	50	330
Splitnose	640	10	1,280
Rougheye	270	120	410
Widow[3]	3,040	0	7,050
Sharpchin	590	200	980
Redstripe	2,050	0	4,120
Shortspine thornyhead[4]	290	210	370
Total	50,940		
Columbia			
Pacific ocean perch	7,100	4,300	9,910
Canary	6,290	3,080	9,510
Yellowtail	11,950	3,370	20,540
Silvergray	550	0	2,460
Bocaccio	920	370	1,470
Darkblotched	2,100	1,530	2,670
Splitnose	1,180	790	1,560
Rougheye	820	550	1,100
Widow[3]	330	180	490
Sharpchin	2,180	850	3,520
Redstripe	3,720	0	7,940
Shortspine thornyhead[4]	2,020	1,650	2,390
Total	39,160		
Eureka[5]			
Pacific ocean perch	220	80	360
Canary	490	0	1,280
Yellowtail	640	0	1,370
Bocaccio	40	10	70
Chilipepper	110	0	280
Darkblotched	540	290	780
Splitnose	530	100	950
Stripetail	670	0	1,570
Shortspine thornyhead[4]	140	30	240
Total	3,380		
Monterey			
Bocaccio	4,980	1,960	8,000
Chilipepper	9,280	5,490	13,070
Yellowtail	650	20	1,280
Canary	220	60	380
Darkblotched	1,410	270	2,550
Splitnose	6,840	4,210	9,470
Shortbelly[3]	24,340	7,710	40,980
Stripetail	4,990	2,570	7,420
Shortspine thornyhead[4]	190	120	250
Total	52,900		
N. Conception			
Bocaccio	830	90	1,580
Chilipepper	200	60	340
Splitnose	3,610	2,660	4,560
Shortbelly[3]	610	60	1,160
Stripetail	2,170	1,000	3,330
Shortspine thornyhead[4]	80	60	110
Total	7,500		

[1]International North Pacific Fisheries Commission.
[2]South of the United States-Canada equidistant line.
[3]A substantial proportion of this stock is known to exist in midwater, and this should not be interpreted as an estimate of total biomass.
[4]A substantial proportion of this stock lies deeper than 250 fathoms, and this should not be interpreted as an estimate of total biomass.
[5]Including the area between lat. 40°25′ and 40°30′N.

Discussion

Results from the 1976 pilot survey (Adams[8]; Gunderson and Nelson, footnote 2) showed that most species of rockfish are characterized by a highly contagious spatial distribution, resulting in a high degree of sampling variability in trawl survey data. Dense, tightly-clustered aggregations were periodically encountered during the survey, and the results from a single large trawl catch can significantly increase both the biomass estimate for a given species and its variance.

Ninety percent confidence intervals around biomass estimates obtained in 1977 typically ranged from ±30 to 150 percent (Table 3), reflecting the same order of variability encountered during the pilot survey, although the extreme ranges obtained for bank rockfish, *S. rufus*, (±233 percent) and blackgill rockfish, *S. melanostomus*, (±213 percent) in 1976 were seldom encountered. The broadest ranges encompassed by 90 percent confidence intervals were around biomass estimates for canary rockfish in the Vancouver and Eureka areas (±168 percent and ±161 percent, respectively), silvergray rockfish in the Vancouver and Columbia areas (±154 percent and ±347 percent, respectively) and chilipepper in the Eureka area (±155 percent).

Estimates of Pacific ocean perch biomass in the Vancouver and Columbia area (±112 percent and ±40 percent, respectively) and yellowtail rockfish in the same areas (±99 percent and ±72 percent) were of intermediate precision, and a recent cohort analysis of Pacific ocean perch stocks (Gunderson[9]) suggests that the point estimates in Table 3 are realistic. Biomass estimates for bocaccio and chilipepper rockfish in the Monterey area are also intermediate in their precision (±61 percent and ±41 percent, respectively) and should be useful in the management of these stocks.

Most estimates of rockfish biomass obtained through demersal trawling are relatively imprecise. Such estimates are valuable at present, when no alternative sources of stock assessment data are available, but will become less valuable as data on commercial catches, CPUE, and age composition become available.

A substantial effort should be made in the future to examine alternative survey strategies for rockfish and to determine the degree of sampling effort required to produce more precise biomass estimates. At present, it seems that more precise estimates could be obtained by reducing the extent of the survey area, using the 1977 survey results to concentrate sampling effort in the most important geographic-bathymetric areas and increasing the number of hauls made within them. The variance within such "index" areas would be lower than that encountered during the 1977 survey, but could still be quite high given the contagious nature of rockfish distributions.

[8]Adams, P. B. 1977. The effect of spatial patterns of rockfish (genus *Sebastes*) on sampling strategies. Unpubl. manuscr., 19 p. Southwest Fisheries Center, NMFS, NOAA, 3150 Paradise Drive, Tiburon, CA 94920.
[9]Gunderson, D. R. 1978. Results of cohort analysis for Pacific ocean perch stocks off British Columbia, Washington, and Oregon, and an evaluation of alternative rebuilding strategies for these stocks. Unpubl. manuscr., 20 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Literature Cited

Alton, M. S. 1972. Characteristics of the demersal fish fauna inhabiting the outer continental shelf and slope off the northern Oregon coast. *In* A. T. Pruter and D. L. Alverson (editors), The Columbia River estuary and adjacent ocean waters, p. 583-634. Univ. Wash. Press, Seattle.

Cochran, W. G. 1962. Sampling techniques. John Wiley and Sons, N.Y. 330 p.

Dark, T. A., M. O. Nelson, J. J. Traynor, and E. P. Nunnallee. 1980. The distribution, abundance, and biological characteristics of Pacific whiting, *Merluccius productus*, in the California-British Columbia region during July-September 1977. Mar. Fish. Rev. 42 (3-4):17-33.

Fraidenburg, M. F., J. E. Smith, W. H. Barss, and T. Jow. 1977. Minimum estimates of the all nation removals, North American trawl species composition and CPUE for "other rockfish" in the northeastern Pacific Ocean. Wash. Dep. Fish. Tech. Rep. 34, 31 p.

Gunderson, D. R. 1977. Population biology of Pacific ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte Sound region, and their response to fishing. Fish. Bull., U.S. 75:369-403.

Hughes, S. E. 1976. System for sampling large trawl catches of research vessels. J. Fish. Res. Board Can. 33:833-839.

Wathne, F. 1977. Performance of trawls used in resource assessment. Mar. Fish. Rev. 39(6):16-23.

Westrheim, S. J. 1967. Sampling trawl catches at sea. J. Fish. Res. Board Can. 24:1187-1202.

The Distribution, Abundance, and Biological Characteristics of Pacific Whiting, *Merluccius productus*, in the California-British Columbia Region During July-September 1977

THOMAS A. DARK, MARTIN O. NELSON, JIMMIE J. TRAYNOR, and EDMUND P. NUNNALLEE

Introduction

The Pacific whiting, *Merluccius productus*, is a cod-like species which ranges from off Mexico northward to Alaska and has been the subject of an intensive foreign fishery since 1966. This fishery occurs mainly off northern California to southern British Columbia during spring, summer, and fall when Pacific whiting form feeding aggregations in waters over the continental shelf and upper slope. Spawning occurs off northern Mexico and southern California during December-April, at which time adult fish are not available to fishermen. Foreign annual catches have exceeded 200,000 metric tons (t) occasionally but have averaged about 167,000 t.

A small U.S. fishery for Pacific whiting took place during 1966-68 off southern Washington where a small factory was receiving hake for reduction to fish meal. The fishery was discontinued in 1968 when a depressed fish meal market forced the plant to close.

Since the United States extended its fishery jurisdiction on 1 March 1977 to 200 miles, there has been an increasing interest and investment on the part of domestic industry in the Pacific whiting resource. The covering legislation, known as the Fishery Conservation and Management Act of 1976 (Public Law 94-265), not only extended jurisdiction but required the development of comprehensive fishery management plans within guidelines set forth by national standards for fishery management and conservation.

These developments have significantly increased the need for detailed scientific information about the resource and have resulted in intensified research effort. In 1975, in anticipation of future information requirements, the Northwest and Alaska Fisheries Center of the National Marine Fisheries Service (NMFS) conducted a joint bottom trawl and hydroacoustic-midwater trawl survey of the Pacific whiting resource in continental shelf and upper slope waters along the coast from California to British Columbia (Dark and Nelson[1]). A similar, but more intensive survey was conducted in 1977. The main objectives of the 1977 survey were to determine the distribution, abundance, and biological characteristics of a variety of rockfish, *Sebastes*, species and Pacific whiting. This paper presents information on the distribution, abundance, and biology of Pacific whiting derived from the 1977 survey data.

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[1]Dark, T., and M. Nelson. 1977. The distribution and abundance of Pacific hake from Vancouver Island, British Columbia, to Monterey Bay, California, during September-October, 1975. Unpubl. manuscr., 45 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Methods

The survey was conducted during 4 July-29 September. It employed four vessels for bottom trawl sampling and one for the hydroacoustic-midwater trawl survey. Operations commenced off Port Hueneme, Calif., (lat. 34°08′N) and were concluded off Kyuquot Bay, B.C. (lat. 50°00′N).[2] This area covers the latitudinal range in which Pacific whiting normally occur in commercial concentrations. The bottom depth range surveyed was 50-260 fathoms (91-475 m), except for the area north of Cape Flattery where the hydroacoustic-midwater trawl survey was extended shoreward to 30 fathoms (55 m). Because of constraints on available vessel time, waters shallower

[2]The area from Cape Flattery, Wash., (lat. 48°30′N) to Kyuquot Bay was surveyed by the hydroacoustic-midwater trawl vessel only.

ABSTRACT—The results of a 1977 trawl-hydroacoustic survey of the distribution and abundance of Pacific whiting, Merluccius productus, *off California, Oregon, Washington, and British Columbia are presented.*

Estimates of biomass are presented by International North Pacific Fisheries Commission (INPFC) statistical areas and depth strata. A total of 1,198,932 metric tons of Pacific whiting were estimated to be present in the survey area, 29.2 percent of which occurred in the INPFC Vancouver area; 29.1 percent in the Columbia area; 30.9 percent in the Eureka area; 10.5 percent in the Monterey area; and 0.2 percent in the Conception area. Only 5.8 percent of the total biomass was estimated by the bottom trawl survey while the remainder was estimated by the hydroacoustic-midwater trawl survey.

Age and length compositions reflected previously established latitudinal stratification of age-size groups with the relative abundance of the older, larger fish increasing from south to north. There were no consistent trends of size or age with depth. Age data revealed a high relative abundance of 4-year-old Pacific whiting. This extraordinarily large 1973 year-class at least partially explains the more than twofold increase in estimated biomass between 1975 and 1977 resource surveys.

than 50 fathoms (91 m) were generally not surveyed. Although Pacific whiting occur in the inner shelf region, it is unlikely that a significant portion of the exploitable resource was present inside the 50 fathom (91 m) isobath. The juvenile whiting biomass was probably underestimated, however, because juveniles occur south of the area surveyed and part of the juvenile population is broadly dispersed within scattering layers, making detection and abundance estimation very difficult.

Bottom Trawl Survey

The bottom trawl survey was conducted during 4 July-27 September beginning off Port Hueneme and ending at Cape Flattery. As described by Gunderson and Sample (1980) the survey area was divided into 14 geographic strata. However, for purposes of analyzing and presenting most survey results for Pacific whiting, the data from these strata were combined and geographic variation is shown only for the five International North Pacific Fisheries Commission (INPFC) statistical areas (Fig. 1) in the survey region. Each INPFC statistical area was subdivided into four depth strata: 50-100, 100-150, 150-200, and 200-260 fathoms (91-183, 183-274, 274-366, and 366-475 m) to examine depth-related differences in abundance and size-age composition. Other details of the methods, vessels, and equipment employed in the bottom trawl survey, are the same as those described by Gunderson and Sample (1980).

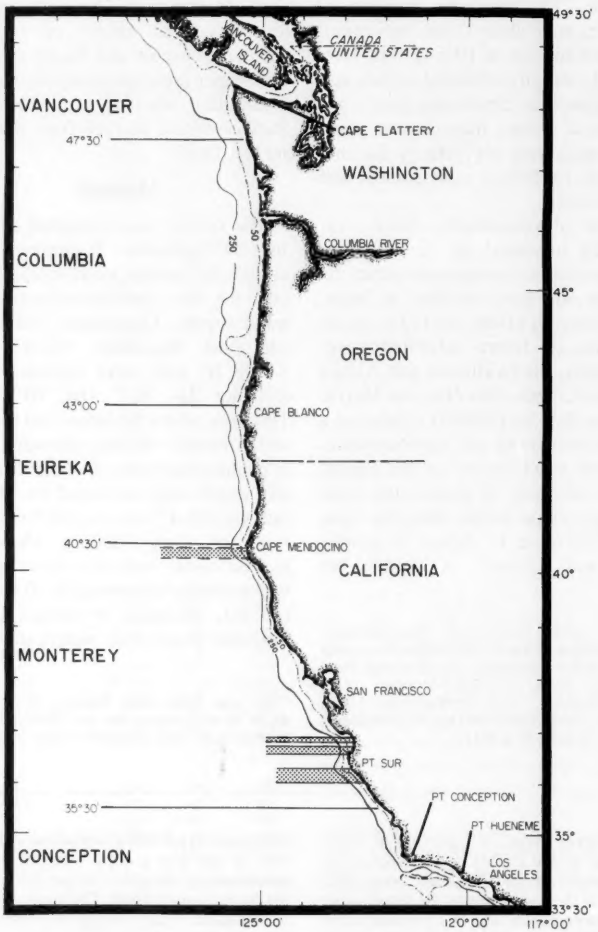

Figure 1.—Bottom trawl survey area showing International North Pacific Fisheries Commission statistical areas. Stippling indicates areas considered to be untrawlable which were not surveyed.

Hydroacoustic-midwater Trawl Survey

The hydroacoustic-midwater trawl survey was conducted between 20 July and 29 September by the NOAA research vessel *Miller Freeman*, a 66-m, 2,200-hp stern trawler. As indicated previously, it surveyed the entire area between Port Hueneme and Kyuquot Bay.

Hydroacoustic Data Acquisition and Processing Equipment and Echo Signal Processing Methods

A hydroacoustic data recording system was used on the California-Washington (Port Hueneme-Cape Flattery) portion of the survey. A computerized data recording and processing system contained in a portable sea-land van was employed while operating between Cape Flattery and Kyuquot Bay. Each system included a 38 kHz echo sounder with three receivers, newly developed echo signal detector units (Marshall and Nunnallee[3]), a Honeywell 5600C[4] seven track FM tape re-

[3]Marshall, W. C., and E. P. Nunnallee. 1980. Detector and synchronization modules for interfacing an echo sounder to a fisheries acoustic data acquisition and processing system. Unpubl. manuscr., 55 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[4]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

corder, and a dual beam transducer housed in a towed V-fin.

Echo sounder system specifications are shown in Appendix I together with calibration data obtained for each system prior to and following its use during the survey. System calibration methods, including those used to monitor system performance at sea, are briefly described in Appendix II. A simplified block diagram of the computerized data recording and processing system is shown in Figure 2. The system's digitally controlled time-varied-gain (TVG) amplifier was developed by Marshall (1977). System operation is synchronized using a control module described by Marshall and Nunnallee[3]. The 40 $\log_{10}$ R signal channels were used only to collect data for measuring individual fish target strength using the dual beam transducer method proposed by Ehrenberg (1974) and discussed by Weimer and Ehrenberg (1975), Ehrenberg (1979), Traynor (1976), and Traynor and Ehrenberg (1979).

The computer system was programmed to implement echo integration simultaneously in each of up to 50 contiguous user selectable depth strata between the transducer and the bottom and in as many as 10 similar bottom referenced depth strata. Echo integration[5] outputs, i.e., integrated echo signal intensities and corresponding estimates of target density for each depth stratum, could be generated as frequently as desired. The echo integration data were collected at a rate of 7.5k samples per second on the 20 $\log_{10}$R signal channel.

The computer system dual beam software consisted of two sets of programs. One acquires and another analyzes single target pulse voltage information. The former, which simultaneously samples each of the 40 $\log_{10}$ R signal channels at 15 k samples per second, accepts single targets on the basis of half amplitude pulse length in the narrow beam and measures maximum pulse voltage in each channel. A file is then produced which contains the peak voltage, range, and half amplitude pulse lengths on both narrow and wide beam channels for each target accepted. The analysis programs utilize this output file together with TVG measurement and other calibration data to: 1) Calculate the effective scattering cross section (σ) for each accepted target and 2) determine mean scattering cross section estimate distributions and their variances. The analysis is done using operator specified noise level and beam pattern threshhold values.

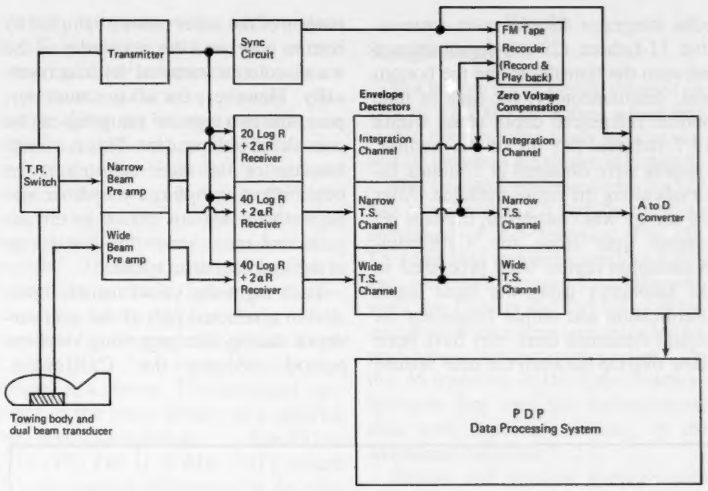

Figure 2. — Block diagram of computerized hydroacoustic data acquisition and processing system.

Midwater Trawl Gear and Accessories

A modified standard Cobb pelagic trawl (Fig. 3) was used to sample midwater echo sign. It was fished with 55-m bridles (2 per wing), 2.1- × 3.0-m steel V-doors, and had a 3.2-cm mesh codend liner.

The trawl was positioned with an Elac cable netsounder system which included an LAZ 17 echo recorder with a DSG scale expander unit and an up-down looking 30 kHz headrope transducer. Netsounder records indicated the trawl's average vertical mouth opening was approximately 7.3 m. The opening varied from 5.5 to 13 m depending upon towing speed and the amount of trawl cable set out. Most trawl hauls were made at a speed of 3.5-5 kn.

Survey Design and Data Collection-Processing Procedures

The survey was conducted during daylight hours along a trackline consisting of a continuous set of zigzag transects spaced at 10 nautical mile intervals. Between Port Hueneme and Cape Flattery, the trackline was normally run between the 50- and 250- fathom (91- and 457-m) isobaths. As mentioned previously, north of Cape Flattery the inshore boundary of the survey was 30 fathoms (55 m). Vessel speed averaged approximately 9 knots and the transducer was towed at an average depth of 15 fathoms (27 m).

During the part of the survey (between Cape Flattery and Kyuquot Bay) when the computer system was aboard the vessel, it was programmed to obtain

[5]The integration method of echo signal processing has been described by Forbes and Nakken (1972) and other authors. In simple form, the relation between the output of an echo integrator and fish density, which is valid for a substantial range of fish densities, is: $I = K\bar{\sigma}\rho$, where I = integrated echo signal intensities (squared echo signal voltages), K = constant dependent upon system parameters, $\bar{\sigma}$ = mean scattering cross section of an individual fish; the target strength, TS, of an object is defined as $TS = 10 \log_{10} (\sigma/4\pi)$, and ρ = number of fish per unit volume.

echo integrator data for each consecutive 11-fathom (20-m) depth stratum between the transducer and the bottom and, simultaneously, for each of nine bottom referenced depth strata within 13.7 fathoms (25 m) of the bottom. Outputs were obtained at 1-minute intervals along the entire trackline. After the survey was completed, the tape recorded data from the California-Washington region were processed in the laboratory using the same depth stratification and output frequency. In certain situations there may have been some overlap between the near bottom portion of the water column sampled by bottom trawl and the remainder of the water column sampled hydroacoustically. However, for all practical purposes the two types of sampling can be considered independent. This is mainly because of the basic constraints on near bottom sampling by hydroacoustic methods that are caused by the angular and range resolution limitations of the hydroacoustic system.

Each night the vessel usually operated in a selected part of the area surveyed during the preceding daytime period. Along the California-Washington coast, the primary objective at night was to detect certain species of rockfish and obtain information on diel changes in their vertical distribution and availability. Also, several nights were devoted to locating mono-specific dispersed aggregations of whiting and collecting target strength data with the dual beam system. The target strength data collection was intensified during the last part of the survey when the computer system was available and the data could be analyzed and examined immediately.

Midwater trawl hauls were made both day and night throughout the survey period to identify echo sign and obtain biological data on whiting, rockfish, and other species. The duration of each haul was determined by the accuracy with which the trawl was positioned, the extent and density of the echo sign, and the apparent efficiency of the trawl as indicated by the net-sounder recording.

Procedures for sorting and sampling midwater trawl catches to determine species composition and obtain length frequency and otolith samples did not differ significantly from those described for the bottom trawl survey by Gunderson and Sample (1980). Length composition was determined for nearly all whiting catches. Except for juvenile fish (<20 cm in length), the data were always segregated by sex.

Expendable bathythermograph (XBT) casts were usually made at each trawl station. In addition, between Port Hueneme and Cape Flattery, there were additional XBT stations at the 50, 100, 150, 200, and 250 fathom (91, 183, 274, 366, and 457 m) isobaths on every other daytime survey transect.

Biomass and Size-Age Composition Estimation

Pacific whiting aggregations were identified by examination of echogram records and trawl species composition data. The biomass for each aggregation was estimated by extrapolating the average biomass per unit surface area estimate. The average was calculated from the individual echo integrator outputs, i.e., the estimates of biomass per unit surface area (D_B) computed at

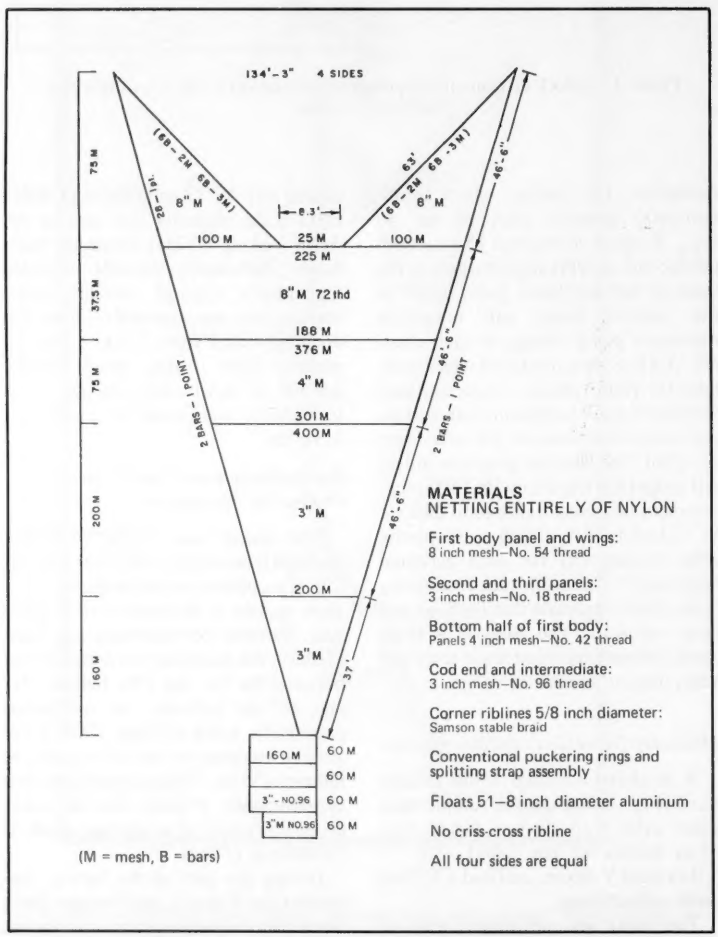

Figure 3.—Diagram of modified Cobb pelagic trawl.

1-minute intervals while sounding on whiting: D_B = kg/100 m² of surface area = $\sum_{i=1}^{n} (R_L - R_U)_i (D_S)_i$, where $(R_L)_i$ and $(R_U)_i$ = the lower and upper boundaries of the ith depth interval between the transducer and the seabed (the computer automatically compensates for differences in interval dimensions caused by changes in bottom depth) and $(D_S)_i$ = volumetric biomass density (kg/100 m³) in the ith depth interval.

The distributions of individual biomass per unit surface area estimates along the transects were used to define the geographic boundaries required for extrapolation of the average density estimates.

During the survey an average target strength estimate of −38 dB/kg was obtained from dual beam data collected at night on dispersed fish aggregations consisting primarily of whiting. However, an estimate of −35 dB/kg was used to calculate density. The higher target strength value which, of course, results in a more conservative (by a factor of two) biomass estimate, was chosen because: 1) The "whiting" aggregations from which the −38 dB estimate was obtained also contained some walleye pollock, *Theragra chalcogramma*, and spiny dogfish, *Squalus acanthias*, and 2) a recent review of fish target strength research studies (Food and Agriculture Organization, 1978) suggests −35 dB is a more accurate estimate for whiting-like species of similar size and morphology. The review included evaluation of a paper (Traynor, In press) which described the work done on the survey that resulted in an estimate of −38 dB.

Major latitudinal differences in the distribution of the whiting resource were shown by estimating the biomass in each of four INPFC statistical areas. These biomass estimates were obtained from separate estimates made for six bottom depth zones in each of 11 latitudinal subareas.

Biomass and associated confidence interval (95 percent) estimation procedures were as follows. For each subarea, biomass (B) was estimated from: $\hat{B} = A\bar{D}$, where A = area over which density estimates were extrapolated, and $\bar{D}$ = mean density per unit surface area (kg/100m²) within the subarea.

Because successive density estimates along the survey transects are serially correlated, and therefore not independent, an estimate of the variance of the mean which uses the sample variance s^2, may not be large enough to yield reliable confidence intervals[6]. To correct for this, variance estimation methods based on cluster sampling theory (Hansen et al., 1953) were used, as suggested by Shotton and Dowd (1975). Each survey transect was treated as a cluster. The estimated variance of the mean density in a subarea was then calculated as: $\mathrm{Var}(\bar{D}) = (\bar{D})^2 (V^2 / T\bar{n}) \{1 + \delta(\bar{n} - 1)\}$ where T is the number of transects in the subarea, $\bar{n}$ is the mean number of density (kg/100 m²) estimates per transect, V^2 is a relative variance term containing both within and between transect variance components, and δ measures the amount of within transect correlation. The variance of the biomass estimate is then $\mathrm{Var}(\hat{B}) = A^2 \mathrm{Var}(\bar{D})$.

To obtain biomass variance estimates for each INPFC statistical area and for the entire survey area, appropriate subarea estimates were summed. The 95 percent confidence interval for each biomass estimate was calculated as: C.I. $= \pm t_{.05} [\mathrm{Var}(\hat{B})]^{1/2}$, where the value of $t_{.05}$ corresponded to the sample size used to estimate B.

The percentage size composition, by sex, of midwater whiting in each INPFC area was estimated by combining unweighted length frequency samples. Length frequencies for juvenile whiting (<20 cm) were obtained from unsexed samples. Age-length keys were derived for each area from the midwater trawl otolith-length samples and applied to the length frequency distributions to obtain percentage age composition estimates. The age composition estimates were made with the sexes combined.

[6]The results of recently completed hydroacoustic survey simulation analyses are being used to help define the magnitutde of this error (Neal Williamson, Northwest and Alaska Fisheries Center, NMFS, NOAA, Seattle, WA 98112. Pers. Commun.).

Results

Sample Density

The bottom trawl survey covered an area of 37,700 km² within which 664 usable bottom trawl hauls were made. Station locations are shown in Figure 4.

The daytime hydroacoustic survey was completed on a 6,464-km trackline composed of 225 transects (Fig. 5). Two-hundred transects, totaling 5,028 km, were run between Port Hueneme and Cape Flattery and 295 hours of hydroacoustic data were tape recorded for post-survey computer processing. On the 25 transects in the Cape Flattery-Kyuquot Bay area the hydroacoustic data were processed directly by the shipboard computer.

Station and selected species catch data for the 116 midwater trawl hauls made during the survey period are summarized in Appendix III. The geographic distribution of the hauls is shown in Figure 6. Hauls 1-83, which included 41 daytime and 42 night hauls, were made during the Port Hueneme to Cape Flattery portion of the survey. Hauls 94-116, which included 9 daytime and 14 night hauls, were made while surveying in the Cape Flattery to Kyuquot Bay area. Hauls 84-93, which were concentrated off Cape Flattery, were made during a comparative hydroacoustic survey conducted from 11 to 16 September with the Polish research vessel *Profesor Siedlecki* and the Canadian research vessel *G. B. Reed*.

Distribution and Abundance

Bottom Trawl Survey

The number of bottom trawl hauls and average catch rates (kg/km trawled) of Pacific whiting are presented in Table 1 by INPFC areas and depth zones. Estimates of biomass, 95 percent confidence intervals, and numbers of trawl hauls by INPFC areas and depths are shown in Table 2. Almost half of the total biomass estimate derived from the bottom trawl survey was in the Columbia area. The next highest abundance was in the Monterey area where 26 percent of the biomass estimated by bottom trawl was found. The

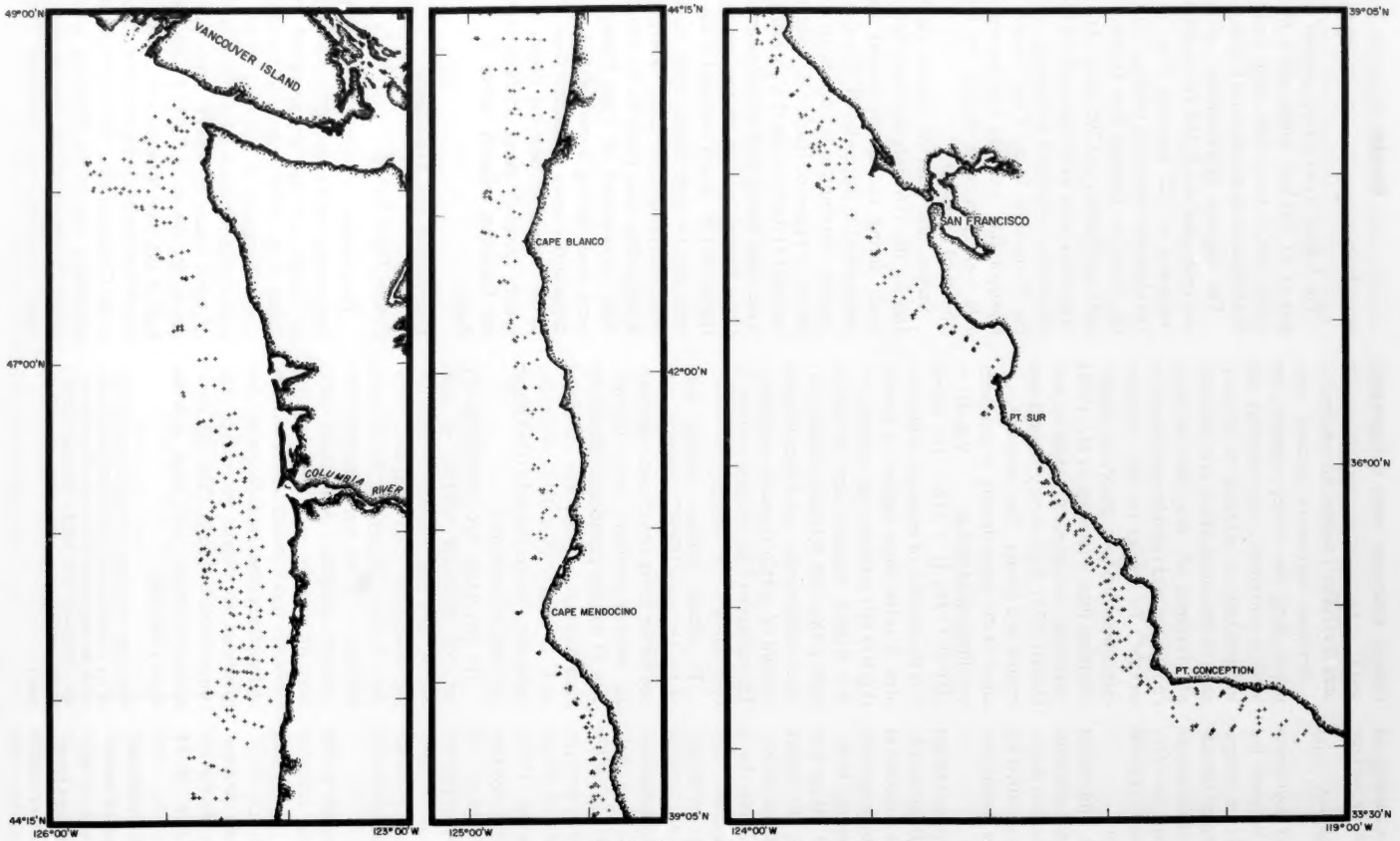

Figure 4.—Geographic distribution of bottom trawl stations.

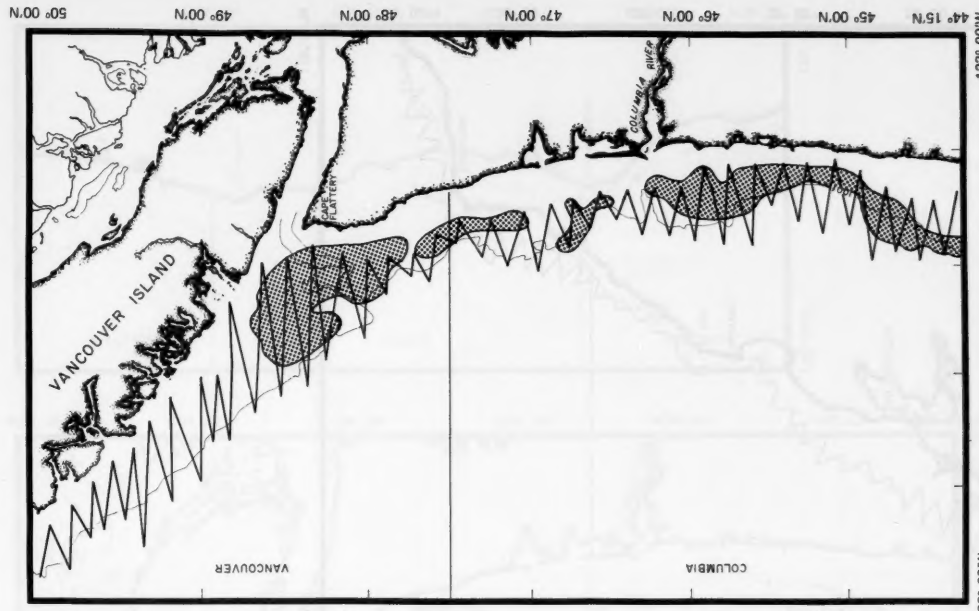

Figure 5.—Hydroacoustic-midwater trawl survey transects and locations of Pacific whiting aggregations (indicated by stippling) for which biomass estimates were made.

relatively small Eureka area was the third most important region and contained 14 percent of the estimated biomass. The relatively low biomass estimate (6,560 t) for the Vancouver area was probably due primarily to the fact that only a small part of the area was surveyed by bottom trawl. The Conception area typically contains relatively small quantities of whiting. Figure 7 presents whiting density contours for the survey area as derived from bottom trawl data.

In all areas, the abundance of whiting near the bottom tended to decrease with increasing depth (Table 2). Overall, 87 percent of the biomass was found on the shelf in waters less than 100 fathoms (183 m), about 7 percent in the 100-150 fathom (183-274 m) depth stratum, 4 percent in the 150-200 fathom (274-366 m) stratum, and 2 percent in the 200-250 fathom (366-457 m) stratum. A similar trend showing decreasing abundance with depth for bottom trawl caught whiting was observed during the 1975 survey.

Confidence intervals (95 percent) associated with area-depth biomass values are as great as ±152 percent of the

Table 1.—Pacific whiting catch per unit effort (kg/km trawled) by International North Pacific Fisheries Commission (INPFC) statistical area and depth stratum.

Depth (fm)	INPFC Area									
	Vancouver		Columbia		Eureka		Monterey		Conception	
	No. hauls	kg/km	No. hauls	kg/km	No. hauls	kg/km	No. hauls	kg/km	No. hauls	kg/km
50-100	32	19.7	105	42.1	21	48.1	78	36.9	28	7.4
100-150	17	6.9	51	9.0	14	9.0	43	13.8	29	10.5
150-200	14	14.5	33	5.8	13	6.0	44	10.7	19	8.5
200-260	7	2.3	40	5.1	12	1.7	41	4.1	25	1.6

Table 2.—Bottom trawl survey estimates of Pacific whiting biomass (t), associated 95 percent confidence intervals, and number of trawl hauls (*n*), by International North Pacific Fisheries Commission (INPFC) statistical area and depth stratum.

Depth (fm)	INPFC Area					Total
	Vancouver	Columbia	Eureka	Monterey	Conception	
50-100						
Biomass	5,680	29,703	8,792	15,546	780	60,501
C.I.	108-11,252	16,936-42,470	0-18,811	6,025-25,067	371-1,190	41,250-79,752
n	32	104	20	78	28	262
100-150						
Biomass	420	1,592	416	1,707	953	5,088
C.I.	110-730	520-2,664	195-637	0-4,310	503-1,403	2,270-7,906
n	17	51	14	43	29	154
150-200						
Biomass	423	800	227	758	540	2,748
C.I.	142-704	318-1,282	52-402	102-1,414	293-787	1,869-3,627
n	14	33	13	44	19	123
200-250						
Biomass	37	822	66	255	123	1,303
C.I.	7-67	496-1,148	0-136	169-341	33-213	955-1,651
n	7	40	12	41	25	125
Total (50-250) biomass	6,560	32,917	9,501	18,266	2,396	69,640
C.I.	0-14,433	19,963-45,868	0-19,724	8,231-28,302	1,744-3,048	53,325-85,953
n	70	228	59	206	101	664

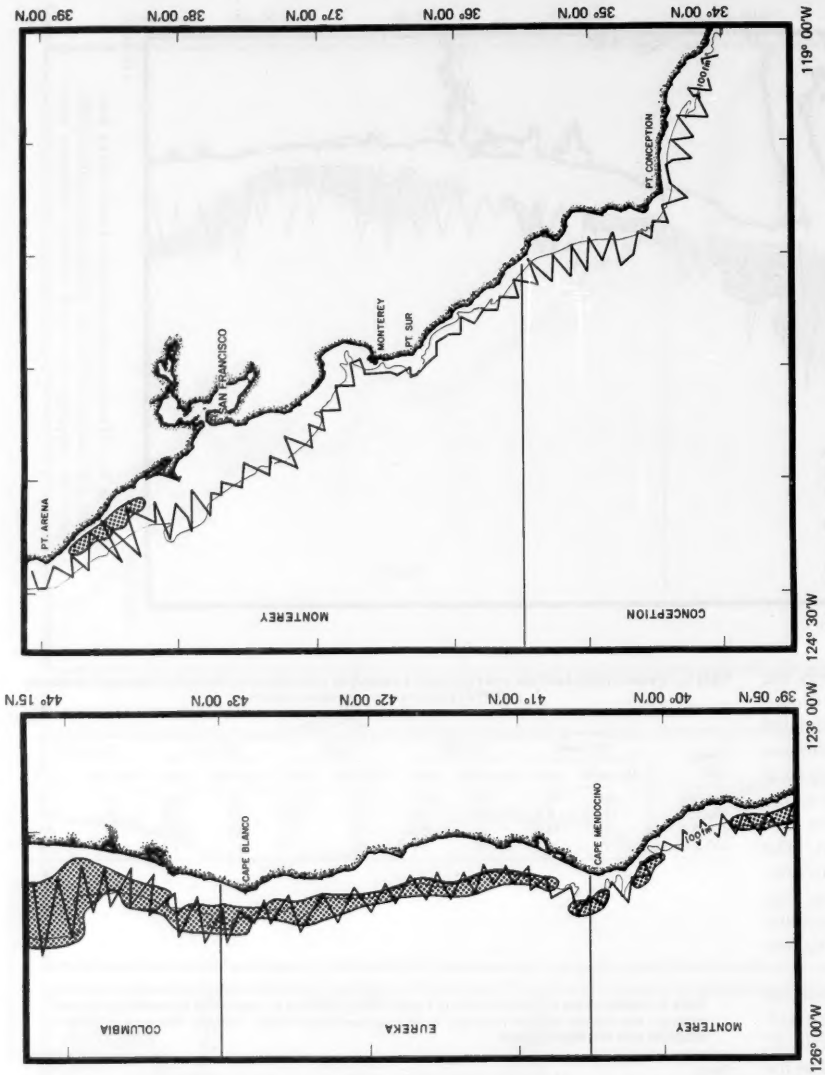

Figure 5.—Continued.

point estimate. While these intervals indicate substantial variation about the biomass estimates, they are generally smaller than those calculated from 1975 survey data, probably because of the increased station density.

Hydroacoustic-Midwater Trawl Survey

The distribution of Pacific whiting aggregations as determined by the hydroacoustic-midwater trawl survey is shown in Figure 5. The INPFC area biomass estimates and associated confidence intervals are shown in Table 3. South of Bodega Bay, Calif., (lat. 38°15'N) where significant sized schools were not located and trawl catches were generally small, it was not feasible to attempt biomass estimation.

Table 3.—Hydroacoustic-midwater trawl survey estimates of Pacific whiting biomass (t) and associated 95 percent confidence intervals, by International North Pacific Fisheries Commission (INPFC) statistical area.

INPFC area (latitude)	Biomass est. (t)	Percent of total	95% C.I.
Monterey (35°30'-40°30'N)	108,087	9.6	±32,949 (30.5%)
Eureka (40°30'-43°00'N)	360,944	32.0	±76,647 (21.2%)
Columbia (43°00'-47°30'N)	316,440	28.0	±68,276 (21.6%)
Vancouver (47°30'-50°30'N)[1]	343,821	30.4	±83,325 (24.2%)
Totals	1,129,292	100.0	±136,375 (12.1%)

[1]Area between lat. 50°00' and 50°30'N not surveyed.

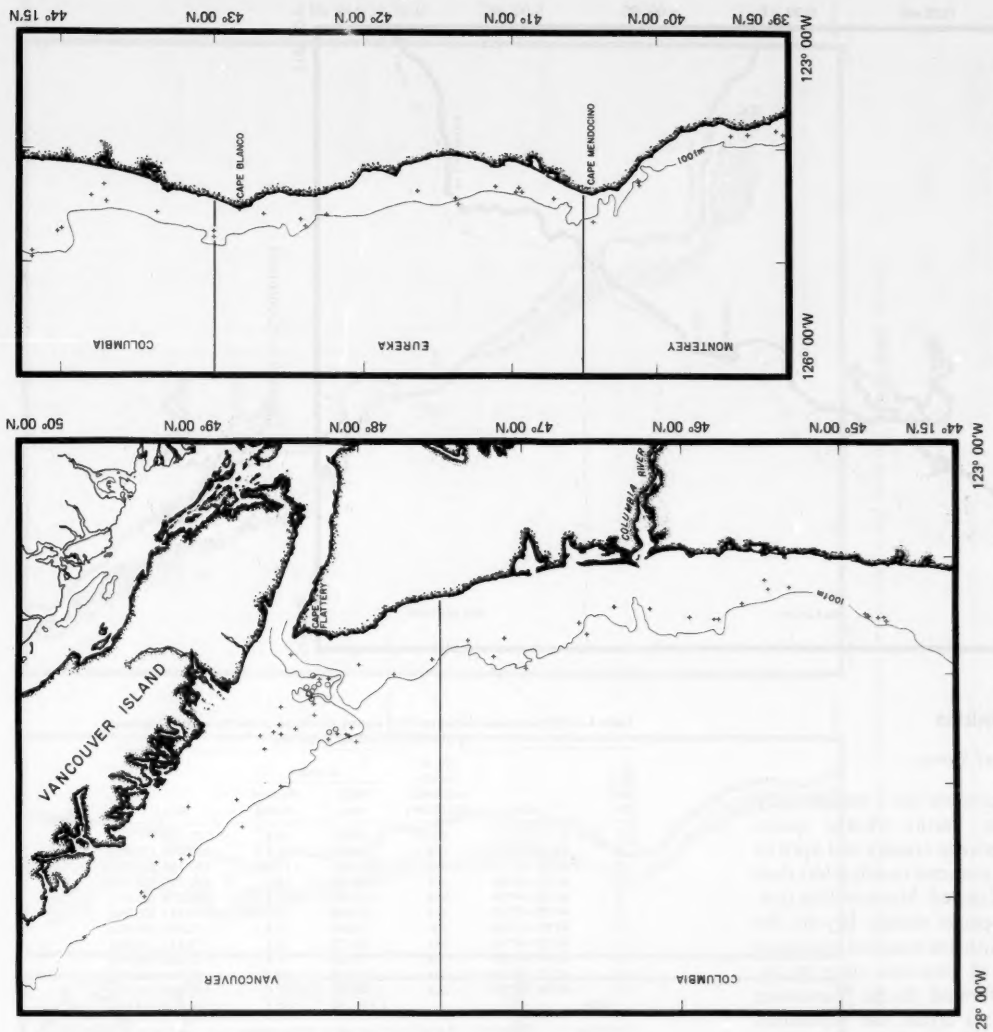

Figure 6.—Geographic distribution of midwater trawl hauls. Hauls off Cape Flattery indicated by circled dots were made during cooperative hydroacoustic intercalibration surveys.

The northernmost portion of the survey region (between lat. 49°00′ and 50°00′ N) was also an area of low abundance.

Except between Cascade Head, Oreg., and the Queets River, Wash., (lat. 45°00′-47°30′ N) whiting were abundant throughout the region from Bodega Bay to southern Vancouver Island (lat. 49°00′ N). Only 5.4 percent of the total estimated biomass was located in the Cascade Head-Queets River area (Table 4).

The distribution of whiting by bottom depth and INPFC area is shown in Figure 8.[7] Abundance was highest in the 50-100 fathom (91-183 m) zone in all INPFC areas and, except in the Eureka area, the total for this zone exceeded that for the entire slope region (100-250 fathoms). Only 13.4 percent of the total biomass in the 50-250 fathom (91-457 m) depth zone was found beyond the 150 fathom (274 m) isobath. Between Cape Flattery and Kyuquot Bay 12 percent (17,290 t) of the biomass was located shoreward of the 50 fathom (91 m) isobath, i.e., between depths of 30 and 50 fathoms (55-91 m).

[7]Ninety-six and one-half percent (1,089,766 t) of the total biomass (1,129,292 t) estimated from the hydroacoustic-midwater trawl survey was located between the 50 and 250 fathom (91-457 m) isobaths. Approximately 1.5 percent (17,290 t) was in the 30 to 50 fathom (55-91 m) depth zone between Cape Flattery and Kyuquot Bay. The remainder (2 percent) was detected when transects occasionally extended slightly outside the depth boundaries (50-250 fathoms) planned for the survey.

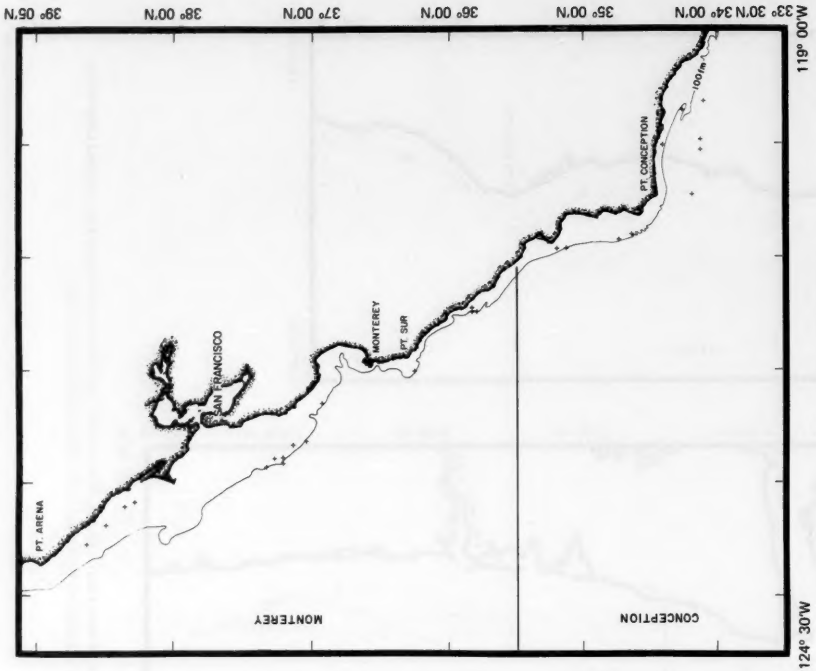

Figure 6.—Continued.

Age Composition

Bottom Trawl Survey

Figure 9 presents age composition by INPFC area. Pacific whiting spawn primarily between January and April so most ages are several months older than actually designated. Many otoliths contained an opaque margin beyond the last distinguishable annulus, indicating the passage of some time since the annulus was formed. In the Vancouver and Columbia areas, the population was dominated by 7-year-old whiting (1970 year class). However, even in those northern areas, where younger fish are relatively less abundant, there was an indication that the 1973 year class (age 4) may be unusually large. The 1973 year class was very abundant in the Eureka area and dominated in the Monterey area. In the Monterey area juvenile fish (less than age 4) composed a substantial portion of the population, and young-of-the-year (age 0) were present. In the Conception area, samples were dominated by age 0 specimens.

Table 4.—Hydroacoustic-midwater trawl survey estimates of Pacific whiting biomass by selected latitudinal subareas.

Sub-area no.[1]	N. latitude	No. of density estimates	Biomass		95% C.I.
		(kg/100m²)	Metric tons	Percent of total	
4	37°07'-38°49'	202	49,227	4.4	±25,705 (52.2%)
5	38°49'-40°16'	299	58,860	5.2	±20,758 (35.3%)
6	40°25'-41°47'	427	191,451	17.0	±60,156 (31.4%)
7	41°47'-43°00'	365	169,493	15.0	±47,710 (28.1%)
8	43°00'-44°08'	849	199,568	17.7	±65,879 (33.0%)
9	44°08'-45°00'	719	55,966	5.0	±14,441 (25.8%)
10	45°00'-45°50'	360	18,604	1.6	± 3,834 (20.6%)
11	45°50'-46°44'	341	26,776	2.4	± 3,415 (12.8%)
12	46°44'-47°30'	39	15,526	1.4	±10,358 (66.7%)
13	47°30'-48°26'	984	201,399	17.8	±77,549 (38.5%)
14	48°26'-49°26'	283	142,422	12.6	±30,808 (21.6%)
Totals			1,129,292	100.1	±136,375 (12.1%)

[1]Subareas 4-13 correspond to the biological sampling strata referred to by Gunderson and Sample (1980).

Percentage age composition was also analyzed by depth strata. Age data were not obtained for all area-depth strata and in the Vancouver and Eureka areas age compositions are available for only one stratum. In the Columbia area, there was a distinct tendency for younger fish (particularly age 4) to become more prevalent with increasing depth. A similar trend occurred in the age composition data from the Monterey area with age 0 and age 2 fish being most numerous in the deepest depth stratum sampled. The age-depth relationship in the Conception area was unclear. Whereas the relative abundance of 2-, 3-, and 4-year-old fish increased with increasing depth, the proportion of age 0 fish decreased markedly. Length frequency data (Table 5) suggest that there was a tendency for the relative abundance of younger fish to decrease with depth in the Vancouver area.

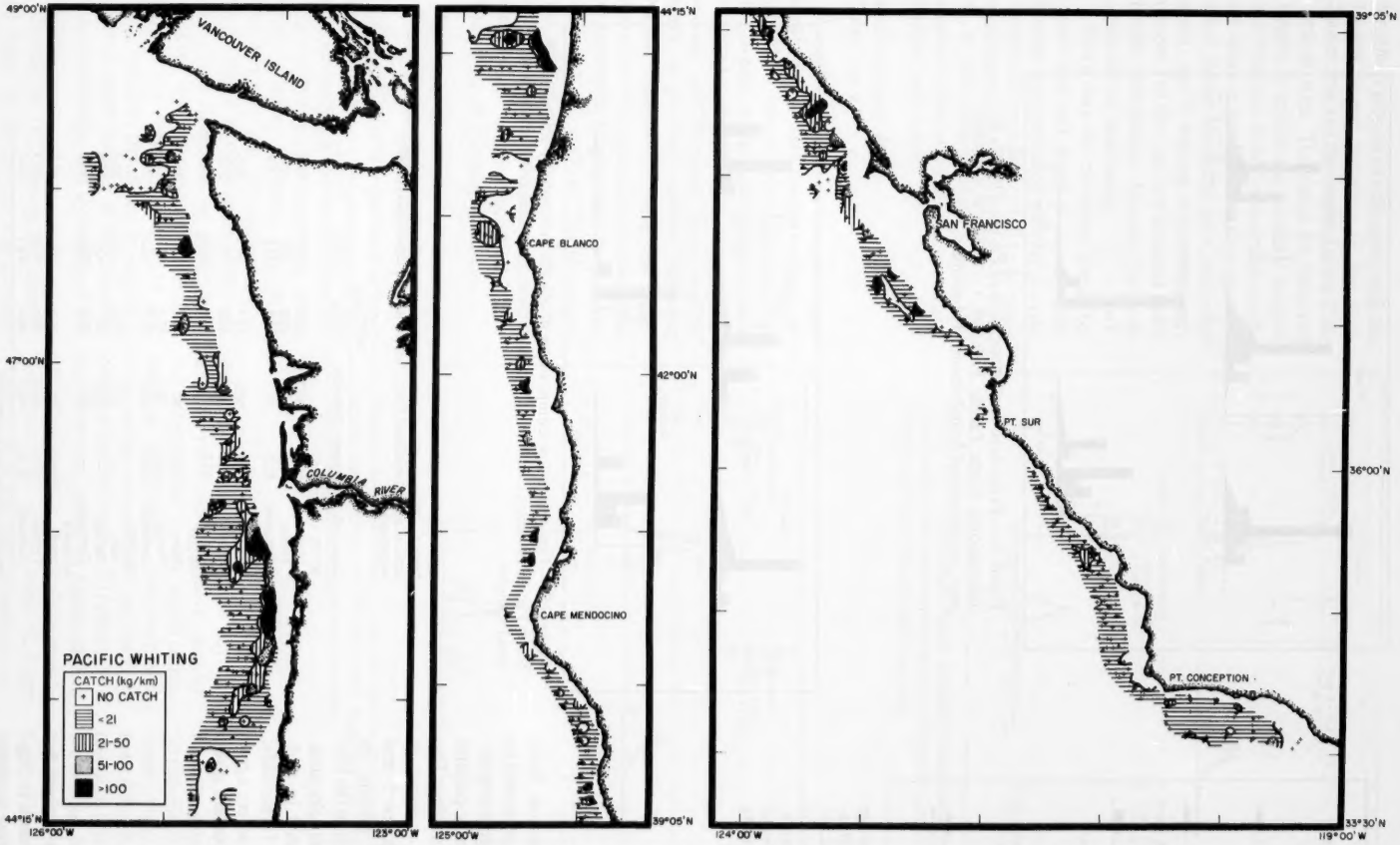

Figure 7.—Pacific whiting biomass density (kg/km) contours as determined from the bottom trawl survey.

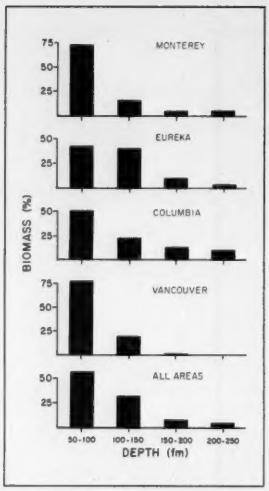

Figure 8.—Percentage distribution, by International North Pacific Fisheries Commission statistical area and depth, of hydroacoustic-midwater trawl survey whiting biomass estimates.

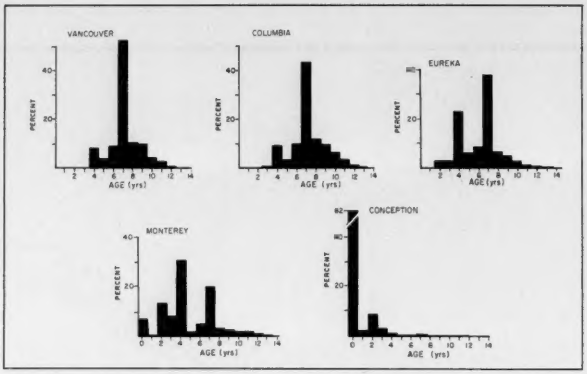

Figure 9.—Percentage age composition of Pacific whiting, by International North Pacific Fisheries Commission statistical area, as determined from bottom trawl samples.

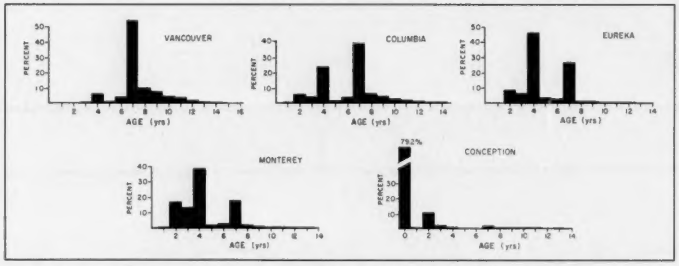

Figure 10.—Percentage age composition of Pacific whiting, by International North Pacific Fisheries Commission statistical area, as determined from midwater trawl samples.

Hydroacoustic-Midwater Trawl Survey

Percentage age composition from midwater trawl samples is presented in Figure 10. The trends in age composition by INPFC area generally parallel those from bottom trawl samples. The most notable differences occurred in the Columbia area, where a few 1- and 2-year-old whiting were present in midwater samples but absent in the bottom trawl samples; in the Eureka area, where 4-year-olds dominated in midwater samples instead of 7-year-olds; and in the Monterey area, where age 0 specimens were found in bottom trawl samples but not in midwater trawl samples.

Length Composition

Bottom Trawl Survey

Percentage length distributions by sex and INPFC area are shown in Figure 11. A north to south cline in mean

Table 5.—Mean lengths of bottom trawl caught whiting by sex, depth stratum, and International North Pacific Fisheries Commission (INPFC) statistical area.

	INPFC area				
Depth (fm)	Vancouver	Columbia	Eureka	Monterey	Conception
50-100					
Male	50.1	50.3	47.3	44.4	34.6
Female	52.1	51.7	48.8	46.7	34.2
Combined	51.5	51.1	48.1	[1]43.9	[1]11.3
100-150					
Male	52.1	50.3	44.7	43.3	28.3
Female	53.8	52.6	45.6	53.3	34.2
Combined	53.2	51.7	45.0	[1]46.2	[1]25.7
150-200					
Male	52.0	48.1	45.4	39.6	31.5
Female	55.4	49.1	47.4	43.7	37.6
Combined	54.6	48.6	46.5	[1]30.3	[1]31.8
200-260					
Male	—	47.2	48.2	41.2	32.4
Female	—	47.8	52.1	43.0	37.0
Combined	—	47.5	50.9	[1]36.6	[1]15.8
All depths					
Male	50.4	50.1	47.1	44.2	30.7
Female	52.5	51.6	48.6	47.0	35.1
Combined	51.8	50.9	48.0	[1]43.1	[1]14.0

[1]Includes unsexed age 0 specimens.

lengths is present in both sexes with the largest means occurring in the Vancouver area and the smallest in the Conception area. The range of observed lengths is smallest in northern samples and becomes wider in the more southern areas as younger fish were encountered. In the Monterey and Conception areas, age 0 whiting were commonly caught, but they are not included in the length distributions because their sex could not be determined.

There was no consistent trend between size and depth of capture. The average size increased with depth in the Vancouver area but tended to decrease with depth in the Columbia area (Table 5). In the more southern regions, the mean size fluctuated in a nonsystematic fashion with depth.

Hydroacoustic-Midwater Trawl Survey

Length compositions from midwater trawl catches were similar to those observed for bottom trawl samples (Fig. 12). Again, the greatest range of sizes occurred in the southern areas and the average size increased from south to north. In previous surveys (Dark and Nelson, footnote 1), there was a tendency for whiting caught in midwater to be somewhat smaller than those taken on or near the bottom. This phenomenon was observed again in the Columbia, Eureka, and Monterey areas, but the opposite situation occurred in the Vancouver and Conception areas.

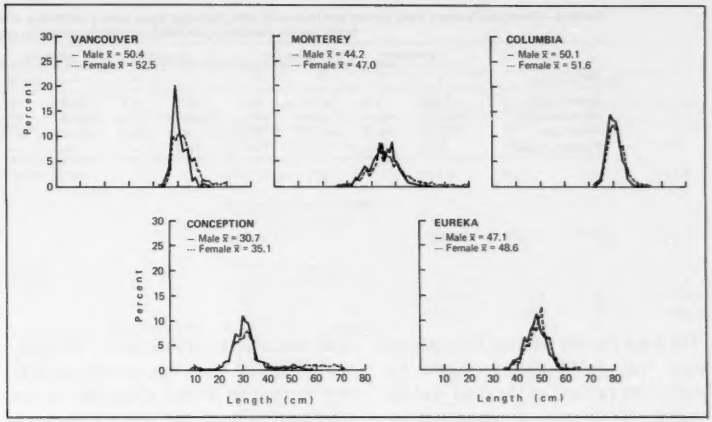

Figure 11.— Percentage length distribution and mean length of Pacific whiting, by sex and by International North Pacific Fisheries Commission statistical area, as determined from bottom trawl samples.

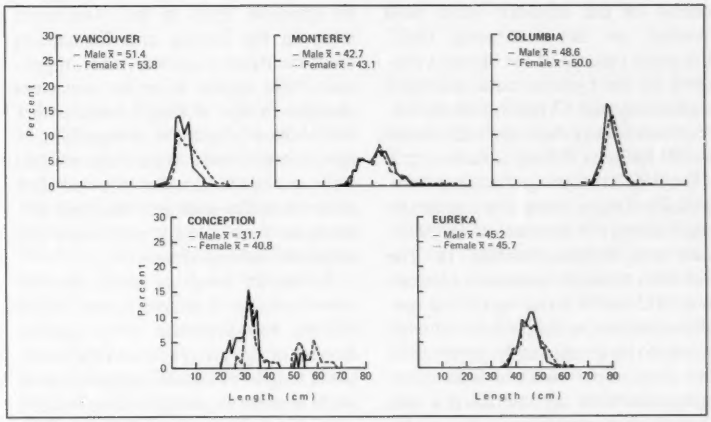

Figure 12.—Percentage length distribution and mean length of Pacific whiting, by sex and International North Pacific Fisheries Commission statistical area, as determined from midwater trawl samples.

Summary and Discussion

The 1977 survey provided a large amount of timely information on the size, geographical and vertical distribution, and biological composition of the Pacific whiting resource. This paper describes only the principal results of the survey. A more detailed analysis of the survey data, and of information available from the commercial fishery and surveys conducted in 1974 and 1975, could be significant in acquiring a better understanding of the distribution, availability, and dynamics of the resource.

During the 1977 survey, the latitudinal range of the species was covered more completely by the hydroacoustic-midwater trawl survey than by the bottom trawl survey which terminated at Cape Flattery. Also, over most of the survey area neither type of survey covered depths less than 50 fathoms (91 m). However, based on historical data and results from the hydroacoustic-midwater trawl survey north of Cape Flattery, it is not unreasonable to assume that the proportion of the total resource inhabiting the area inside the 50 fathom (91 m) isobath was relatively small. Also, since a very small proportion of the total biomass estimate for the resource was derived from trawling on the bottom, it is reasonable to conclude that the lack of bottom trawling north of Cape Flattery did not significantly influence survey results.

Table 6.—Combined bottom trawl survey and hydroacoustic-midwater trawl survey estimates of Pacific whiting biomass (t) by International North Pacific Fisheries Commission (INPFC) statistical area.

	Vancouver		Columbia		Eureka		Monterey		Conception		Total	
Item	t	%	t	%	t	%	t	%	t	%	t	%
Bottom trawl	6,560	1.9	32,917	9.4	9,501	2.6	18,266	14.5	2,396	100.0	69,640	5.8
Hydroacoustic	343,821	98.1	316,440	90.6	360,944	97.4	108,087	85.5	—	—	1,129,292	94.2
Area totals	350,381	100.0	349,357	100.0	370,445	100.0	126,353	100.0	2,396	100.0	1,198,932	100.0
Percent of total	29.2	—	29.1	—	30.9	—	10.5	—	0.2	—	99.9	—

The total Pacific whiting biomass estimate was 1,198,932 t (Table 6). Ninety-four percent of the total was estimated from the hydroacoustic-midwater trawl survey. The biomass was distributed almost evenly among the Vancouver, Columbia, and Eureka areas, with small fractions occurring in the Monterey and Conception areas. Both the midwater and on-bottom components of the resource were most abundant on the continental shelf. Fifty-eight percent of the biomass estimated by the hydroacoustic-midwater trawl survey and 87 percent of the bottom trawl survey estimate were inside the 100 fathom (183 m) isobath.

The 1977 biomass estimate is substantially larger than the generally comparable 1975 estimate of 444,974 t (Dark and Nelson, footnote 1). The more than twofold increase in biomass from 1975 to 1977 can be at least partially explained by the presence of what appears to be an unusually strong 1973 year class. Four-year-old hake were highly abundant in the Eureka and Monterey areas and were also a significant part of the population in more northern areas. This year class could be an important component of the population through 1980. The increase in biomass estimates between 1975 and 1977 cannot be fully ascribed to addition of the 1973 year class because other factors, such as changing availability to the capture gear and sampling variability, could also have resulted in the observed difference. The 1970 year class was very abundant, but it is 10 years old and the effects of fishing and natural mortality have reduced it to relatively low numbers.

Analysis of age data revealed the typical latitudinal stratification of ages, with fish less than age 4 only weakly represented or absent altogether in the northern part of the survey area. A comparison of age compositions in bottom trawl samples by depth showed a tendency for younger age groups to be more prevalent with increasing depth in the Columbia and Monterey INPFC areas, but length composition suggests an opposite trend in the Vancouver area. In the Eureka and Conception areas the trend is unclear, and, in general, there appear to be no consistent changes in age or length composition with bottom depth. A comparison of age compositions from bottom and midwater trawl samples showed they were basically similar. Observed differences were usually small and not consistent among areas.

A broader range of sizes was observed in the southern areas which reflects the presence of a greater number of age groups than in the north. Mean length, of course, increased from south to north as young whiting became relatively less abundant. There was no consistent trend in mean size with depth.

The survey demonstrated that it is not feasible to attempt to estimate either biomass or an index of abundance for the whiting resource from bottom trawl surveys alone. As opposed to the more than twofold increase in abundance estimated to have occurred between 1975 and 1977, the results of the bottom trawl surveys indicate a 66 percent decrease in abundance occurred during the 2-year period, i.e., the bottom trawl survey biomass estimates in 1975 and 1977 were 207,626 t and 69,640 t, respectively.

Literature Cited

Ehrenberg, J. E. 1974. Two applications for a dual-beam transducer in hydroacoustic fish assessment systems. *In* Proc. 1974 IEEE Conf. Engr. Ocean Environ., p. 152-155.

———. 1979. The dual-beam system—a technique for making *in situ* measurements of the target strength of fish. Proc. Inst. Acoustics Specialist Meeting on Acoustics in Fisheries, Sept. 26-27, 1978, Hull, U.K.

Food and Agriculture Organization. 1978. Report of the meeting of the working party on fish target strength, Aberdeen, Scotland, 13-16 Dec. 1977. Food Agric. Organ. U.N., Advis. Comm. Mar. Resour. Res., ACMRR: 9/78/ Inf. 14, 27 p.

Forbes, S. T., and O. Nakken (editors). 1972. Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO Man. Fish. Sci. 5, 138 p.

Gunderson, D. R., and T. M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev. 42(3-4):2-16.

Hansen, M. H., W. N. Hurwitz, and W. G. Madow. 1953. Sample survey methods and theory. Volume 1, Methods and applications. John Wiley & Sons, Inc., N.Y., 638 p.

Marshall, W. C. 1977. A prototype precision time-varied-gain amplifier for an echo sounder receiver. Biomed. Sci. Instrum. 13:5-7, 9-12.

Shotton, R., and R. G. Dowd. 1975. Current research in acoustic fish stock assessment at the Marine Ecology Laboratory. Int. Comm. Northwest Atl. Fish., ICNAF Res. Doc. 75/16, 17 p.

Traynor, J. J. 1976. Studies on indirect and direct methods of *in situ* fish target strength measurement. *In* Acoustic surveying of fish populations, Inst. Acoustics, Underwater Acoustic Group, Proceedings of the Specialist Meeting, Dec. 17, 1975, Lowestoft, U.K., 21 p. Univ. Birmingham, Birmingham, U.K.

———. In press. Further studies of dual beam target strength measurement. Food Agric. Organ. U.N., FAO Spec. Tech. Rep.

———, and J. E. Ehrenberg. 1979. Evaluation of the dual beam acoustic fish target strength measurement method. J. Fish. Res. Board Can. 36:1065-1071.

Weimer, R. T., and J. E. Ehrenberg. 1975. Analysis of threshhold-induced bias inherent in acoustic scattering cross-section estimates of individual fish. J. Fish. Res. Board Can. 32:2547-2551.

Appendix I

Basic echo sounder system specifications and calibration data.

Item	Specifications		Item	Calibration Data			
	[1]System 1	[2]System 2		[1]System 1	[1]System 1	[2]System 2	[2]System 2
Frequency	38 kHz	38 kHz	Calibration date	6/30/77	9/6/77	9/8/77	10/3/77
Transducer			Water temperature (°C)	18.8	19.8	19.8	16.0
Dimensions	23 cm, circular	44 cm, circular	Source level				
Material	barium titanate	barium titanate	(dB//1 mpa at 1 m)	217.9	217.1	226.9	227.3
Beam width (between-3dB pts.)							
Narrow beam	11°	6°	Transducer(narrow beam)				
Wide beam	50°	25°	transmitting sensitivity				
			(dBmpa/V at 1 m)	169.4	168.6	173.4	173.7
Directivity Index							
Narrow beam	22.6 dB	26.7 dB	Transducer receiving				
Wide beam	12.0 dB	18.2 dB	sensitivity (dBV/mpa)				
			Narrow beam	−177.3	−176.8	−177.0	−177.3
Transmitter			Wide beam	−191.4	−190.9	−161.5	−161.8
Type	Simrad EK 38 A	Instruments, Inc. (Model SPG-4B)	System receiving sensitivity				
Nominal power output	1 kw	1 kw and 5 kw	at 30 m (dBV/mpa)				
Nominal pulse length	0.6 ms	0.6 ms	Narrow beam				
Pulse repetition rate	24, 48, and 96/min	60/min(selectable,1-99/min)	(20 logR + 2∝ R)	−138.8	−139.3	−155.4	−150.6[3]
			Narrow beam				
Receiver (TVG Amplifiers)			(40 logR + 2∝ R)	−140.3	−141.0	−147.2	−151.2[3]
Narrow beam (20 logR + 2∝ R)	Simrad EK 38A	Ithaco (custom design)	Wide beam				
Narrow beam (40 logR + 2∝ R)	Simrad EK 38A	Ithaco (custom design)	(40 logR + 2∝ R)	−140.7	−140.5	−147.2	−146.8
Wide beam (40 logR + 2∝ R)	Simrad EK 38A	Ithaco (custom design)					
TVG control	Analog	Digital					
Echo recorder	Simrad EK 38A	Universal Graphics PGR					
Towed V-fin	Braincon (4-ft)	Edo-Western Model 6315					
Towing cable (faired)	2 cm; 13 conductors	2 cm; 13 conductors					

[1]Used with data recording system during Port Hueneme, Calif., to Cape Flattery, Wash., part of survey.
[2]Used with computerized data recording and processing system during Cape Flattery to Kyuquot Bay, Vancouver Island, part of survey.
[3]System gain adjusted during survey.

Appendix II — Hydroacoustic System Calibration Methods

In addition to the calibration of specific system components, it is desirable to calibrate the entire system as a unit because different components of the system may affect the parameters of others. For example, the gain of a preamplifier may be affected by connecting a transducer to its input leads. Therefore, in addition to the transmitted power, the receiving response of the entire system is the primary calibration information required, i.e., what is the voltage detected by the computer, as a function of range, on each signal channel for a known signal intensity at the face of the transducer?

The following procedure is used to calibrate the system. The source level of the system is measured using standard calibration techniques. Using this source level, the intensity that would be returned from an acoustic target having a reference target strength (−30 dB) at a reference depth (30 m) is calculated (accounting for two-way spreading and absorption loss). A calibration transducer is then used to produce a sound pulse (equal in length to that used during data collection) of the calculated intensity at the transducer face. An internal calibration oscillator is then switched on and adjusted so that the resultant receiver output voltage at the reference depth equals that from the acoustic pulse. The calibration oscillator input signal to the receiver then corresponds to an ech from a target of the reference target strength at the reference depth. The output voltage of the receiver can then be monitored at all depths to determine changes in the system gain characteristics.

Time-varied-gain (TVG) characteristics for each receiver are measured using a computer program which samples the signal from the calibration oscillator at 1-m intervals. The system gain (G) at each sampling point is calculated by referencing the receiver output voltage to the input voltage from the calibration oscillator and, expressed in decibels:

$G = 20 \log_{10}(Vo/Vi)$, where Vo and Vi are output and input voltages, respectively. Deviations from the theoretically correct TVG are then determined by subtracting the actual, measured TVG values from the correct values. To be useful these deviations must be referenced to a particular point. This is accomplished by subtracting the TVG correction at a given point from all deviations. The deviation from ideal TVG is then 0 dB at the given point which serves as the reference point. The resultant TVG correction values (deviations from ideal TVG) thus obtained are independent of sounder gain. Since the calibration oscillator is set up to simulate a −30 dB target at 30 m, the usual procedure is to reference the TVG to 30 m.

In addition to the system calibration measurements made just prior to and after each part of the survey, possible variation in system performance was continuously, i.e., every 1.5 hours, measured at sea. This was done by measuring (and tape recording as a back-up procedure) the output of a known signal input to each receiver's preamplifier. This allowed any change in system gain or TVG characteristics to be readily detected. The known signal input was supplied by a calibration oscillator which was an integral part of both systems.

Appendix III

Summary of trawl station and catch data for hydroacoustic/midwater trawl survey.

Haul no.	Date	Start position Lat(N)	Start position Long(W)	INPFC area	Time of day (h; PDT)	Av. depth (fm) gear/ bottom	Duration (h)	Distance fished (n. mi.)	Catch (lb) of selected species (T = catch < 1 lb) Pac. whiting	Rockfish Bocaccio	Rockfish Chili-pepper	Rockfish Shortbelly	Rockfish Splitnose	Rockfish Canary	Rockfish Yellowtail	Rockfish Pac. ocean perch	Rockfish Widow	Rockfish Redstripe	N. anchovy	Eulachon	Pac. herring	Walleye pollock	Spiny dogfish
1	7/20	34°06'	119°40'	Conception	1400	120/125	0.9	3.4	29	—	—	37	—	—	—	—	—	—	T	—	—	—	T
2	7/20	34°15'	119°45'	Conception	0000	99/100	0.5	1.7	8	8	2	8	T	—	—	—	—	—	T	—	—	—	—
3	7/21	34°07'	119°59'	Conception	0700	77/82	0.5	1.9	—	—	—	—	—	—	—	—	—	—	100	—	—	—	—
4	7/21	34°07'	120°04'	Conception	1400	140/160	0.5	1.4	4	—	—	—	—	—	—	—	—	—	43	—	—	—	—
5	7/22	34°23'	120°00'	Conception	0200	125/140	0.7	2.5	13	3	—	—	2	—	—	—	—	—	T	—	—	—	1
6	7/22	34°10'	120°28'	Conception	1100	65/70	0.8	2.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	7/22	34°42'	120°52'	Conception	2300	97/99	1.0	3.5	13	13	114	10	—	—	—	—	2	—	—	—	—	—	11
8	7/23	34°38'	120°49'	Conception	0400	64/71	0.3	0.8	4	3	2	T	—	—	—	—	—	—	—	—	—	—	—
9	7/23	35°07'	120°56'	Conception	1500	95/104	0.3	0.8	46	—	3	5	—	—	—	—	—	—	—	—	—	—	—
10	7/24	35°10'	120°56'	Conception	0100	89/92	1.0	3.2	120	17	3	90	22	—	—	—	—	—	—	—	—	—	292
11	7/24	35°44'	121°29'	Monterey	1300	35/250	0.9	3.1	—	T	—	2	—	—	—	—	—	—	—	—	—	—	—
12	7/24	35°47'	121°27'	Monterey	1700	49/54	0.8	2.3	—	—	—	—	—	—	8	—	—	—	—	—	—	—	—
13	7/25	35°47'	121°29'	Monterey	0200	116/120	0.5	1.7	240	—	—	—	27	—	—	—	—	—	—	—	—	—	4
14	7/25	36°16'	122°01'	Monterey	1000	65/100	1.2	3.7	—	250	—	—	—	—	287	—	33	—	—	—	—	—	—
15	7/26	36°55'	122°19'	Monterey	1400	145/165	0.2	0.5	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16	7/26	37°08'	122°43'	Monterey	2100	154/160	1.0	3.2	620	—	—	18	468	—	—	—	—	—	—	—	—	—	1
17	7/27	37°03'	122°40'	Monterey	0400	172/181	1.0	3.0	219	—	—	T	240	—	—	—	2	—	—	—	—	—	—
18	7/27	37°13'	122°48'	Monterey	1000	134/135	0.5	1.8	924	41	58	8,931	—	—	—	—	—	—	—	—	—	—	—
19	7/27	37°21'	122°52'	Monterey	1700	103/105	0.5	1.7	20	—	—	7,880	—	—	—	—	—	—	—	—	—	—	—
20	7/27	37°16'	122°49'	Monterey	2300	74/102	0.7	1.8	65	6	—	792	—	—	—	—	—	—	—	—	—	—	—
21	7/28	37°14'	122°50'	Monterey	0200	125/155	0.6	1.6	17	—	—	5	—	—	—	—	—	—	—	—	—	—	—
22	7/29	38°15'	123°10'	Monterey	1400	52/53	0.3	0.9	10,450	6	—	—	—	—	—	—	—	—	—	—	—	—	51
23	7/29	38°21'	123°13'	Monterey	0000	40/51	2.0	6.2	457	17	—	—	—	—	—	—	—	—	—	—	—	—	166
24	7/30	38°30'	123°34'	Monterey	1000	59/64	0.4	1.3	7,340	21	—	—	—	—	—	—	—	—	—	—	14	—	552
25	7/31	38°37'	123°33'	Monterey	0100	46/63	2.0	6.8	99	—	—	—	—	—	—	—	—	—	—	—	T	—	110
26	7/31	39°11'	123°54'	Monterey	1300	77/80	1.0	2.9	487	—	—	—	—	74	—	—	—	—	—	—	—	—	12
27	8/1	39°05'	123°57'	Monterey	0100	129/133	0.5	1.8	46	6	213	34	46	—	—	—	—	—	—	—	—	—	—
28	8/1	39°23'	123°57'	Monterey	0500	134/138	0.5	1.2	199	—	—	—	2	—	—	—	—	—	—	—	—	—	—
29	8/1	39°31'	123°58'	Monterey	0900	172/177	0.2	0.7	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	8/1	40°07'	124°20'	Monterey	1900	104/160	0.8	2.6	927	—	—	—	—	—	—	—	—	—	—	—	—	—	2
31	8/2	40°08'	124°17'	Monterey	0600	78/145	0.3	1.3	343	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32	8/2	40°21'	124°38'	Monterey	1400	90/160	0.4	1.2	2,308	—	—	—	—	—	—	—	—	—	—	—	—	—	17
33	8/3	40°44'	124°17'	Eureka	0400	48/51	0.6	1.9	1,207	—	—	—	—	5	—	—	60	—	—	—	—	—	268
34	8/3	41°07'	124°21'	Eureka	1000	60/82	0.3	1.2	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—
35	8/3	40°57'	124°24'	Eureka	2100	54/100	0.6	2.0	347	—	—	—	—	—	2	—	12	—	—	—	—	—	29
36	8/4	40°58'	124°21'	Eureka	0300	44/68	1.5	5.3	1,685	—	—	—	—	—	—	—	—	—	—	—	—	—	62
37	8/4	40°59'	124°24'	Eureka	0800	68/100	0.8	1.8	1,353	—	—	—	—	—	6	—	—	—	—	—	—	—	36
38	8/11	41°23'	124°30'	Eureka	1400	94/127	0.5	1.7	1,282	—	—	—	—	—	—	—	—	—	—	—	—	—	—
39	8/11	41°44'	124°24'	Eureka	2200	52/60	0.5	1.5	286	—	—	—	—	4	—	—	—	—	—	T	—	—	—
40	8/12	41°24'	124°27'	Eureka	0300	67/74	0.7	1.9	104	—	—	—	—	5	—	—	3	—	—	—	—	—	3
41	8/12	42°16'	124°35'	Eureka	1400	88/95	0.2	0.8	2,923	—	—	—	—	—	—	—	—	—	—	—	—	—	27
42	8/12	42°25'	124°42'	Eureka	2200	47/56	1.1	3.8	77	—	—	—	—	—	5	—	155	—	—	—	—	—	1
43	8/13	42°27'	124°38'	Eureka	0300	43/50	0.5	1.6	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—
44	8/13	42°43'	124°36'	Eureka	0900	53/54	0.6	1.8	—	—	—	—	—	—	—	—	—	—	—	13	T	—	—
45	8/13	43°00'	124°48'	Eureka	1500	82/84	0.7	2.4	66	—	—	—	—	—	8	—	—	4	—	T	—	—	—
46	8/13	43°00'	124°48'	Eureka	2200	75/80	0.6	1.6	203	—	—	—	—	—	39	—	—	14	—	10	—	—	—
47	8/14	43°25'	124°35'	Columbia	2300	71/80	0.8	2.6	798	—	—	—	—	22	80	—	29	2	—	—	—	—	—
48	8/15	43°45'	124°28'	Columbia	1400	71/72	0.5	1.5	2	15	—	4	—	—	5	—	13	316	—	—	—	—	—
49	8/15	43°46'	124°20'	Columbia	1800	57/60	0.6	1.8	409	—	—	—	—	—	—	—	—	1	—	T	T	—	—
50	8/16	43°52'	124°26'	Columbia	0200	49/53	0.4	0.9	668	—	—	—	—	3	39	—	1,005	—	—	—	—	—	—
51	8/17	44°12'	124°55'	Columbia	1100	77/79	0.6	2.1	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—
52	8/17	44°12'	124°58'	Columbia	1400	141/151	0.4	1.3	431	—	—	—	—	—	—	—	—	—	—	—	—	—	—
53	8/18	44°00'	124°43'	Columbia	0100	39/64	0.6	2.6	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
54	8/18	44°01'	124°44'	Columbia	0400	34/64	0.7	2.3	2	—	—	—	—	—	—	—	—	—	—	2	—	—	—
55	8/18	44°46'	124°35'	Columbia	2100	54/100	1.0	3.5	3	—	—	—	—	—	—	—	—	—	—	1	—	—	—
56	8/18	44°49'	124°34'	Columbia	0000	133/136	1.0	2.7	119	—	—	—	T	—	—	—	—	—	—	—	—	—	—
57	8/19	44°47'	124°34'	Columbia	1500	116/118	1.8	5.3	246	—	—	—	—	—	—	—	—	—	—	—	—	—	—
58	8/20	44°52'	124°32'	Columbia	0300	145/150	1.0	2.8	30	—	—	—	—	—	—	—	—	—	—	—	—	—	—
59	8/21	44°50'	124°33'	Columbia	0000	148/152	2.3	6.0	94	—	—	—	2	—	—	—	—	—	—	—	—	—	—
60	8/21	45°22'	124°16'	Columbia	1100	88/98	0.7	2.3	26	—	—	—	—	—	—	—	—	—	—	6	—	—	—

Appendix III.-Continued.

Haul no.	Date	Start position Lat(N)	Start position Long(W)	INPFC area	Time of day (h; PDT)	Av. depth (fm) gear/ bottom	Duration (h)	Distance fished (n. mi.)	Catch (lb) of selected species (T = catch<1 lb) Pac. whiting	Rockfish Bocaccio	Rockfish Chilipepper	Rockfish Shortbelly	Rockfish Splitnose	Rockfish Canary	Rockfish Yellowtail	Rockfish Pac. ocean perch	Rockfish Widow	Rockfish Redstripe	N. anchovy	Eulachon	Pac. herring	Walleye pollock	Spiny dogfish
61	8/21	45°30'	124°18'	Columbia	1700	99/100	0.7	2.3	928	—	—	—	—	—	—	—	—	—	—	2	—	—	—
62	8/22	45°32'	124°12'	Columbia	0400	58/74	0.5	1.8	23	—	—	—	—	—	—	—	520	—	—	1	—	—	4
63	8/22	45°41'	124°25'	Columbia	1200	105/107	1.2	3.6	1,094	—	—	—	—	—	—	—	—	—	—	13	—	—	—
64	8/22	45°52'	124°33'	Columbia	2300	62/74	0.8	2.8	—	—	—	—	—	—	—	—	28	—	—	—	—	—	—
65	8/23	45°53'	124°34'	Columbia	0300	56/84	0.8	2.9	2	—	—	T	—	—	—	—	7	—	—	4	—	—	—
66	8/23	45°58'	124°32'	Columbia	1200	85/86	1.0	3.9	1,156	—	—	—	—	—	—	1	2	—	—	17	—	—	—
67	8/24	46°13'	124°28'	Columbia	0100	63/83	1.0	3.0	199	35	—	—	—	—	1,580	—	2,988	150	T	T	—	—	3
68	8/24	46°40'	124°40'	Columbia	1800	80/81	0.1	0.4	30	—	—	—	—	—	13	—	—	—	—	8	—	—	—
69	8/25	46°29'	124°27'	Columbia	0300	65/70	1.0	3.0	74	—	—	—	—	2	63	—	540	—	—	T	T	—	—
70	8/25	44°44'	124°35'	Columbia	0900	71/73	0.6	2.1	8,970	—	—	—	—	—	14	—	29	—	—	7	—	—	—
71	8/26	46°59'	124°58'	Columbia	0000	85/90	1.0	3.3	48	41	—	—	—	—	374	—	1,070	79	—	—	—	—	5
72	8/26	47°08'	124°43'	Columbia	1900	60/61	0.8	2.6	13	—	—	—	—	—	37	—	—	—	—	11	14	—	—
73	8/27	47°12'	124°53'	Columbia	0100	91/95	1.0	3.5	244	16	—	—	—	5	135	—	—	—	—	T	—	—	1
74	8/27	47°23'	124°46'	Columbia	0400	68/74	0.8	2.9	176	—	—	—	—	7	17	—	—	—	—	—	1	—	—
75	8/27	47°37'	124°56'	Vancouver	1000	80/83	0.1	0.3	497	—	—	—	—	—	3	—	—	—	—	2	T	—	—
76	8/27	48°00'	124°59'	Vancouver	1900	57/65	1.0	4.3	2,826	—	—	—	—	—	51	—	140	—	—	—	—	—	2
77	8/28	47°52'	125°02'	Vancouver	0200	81/82	0.7	3.1	95	—	—	—	—	30	502	—	—	—	—	—	—	7	6
78	8/28	48°04'	125°32'	Vancouver	1100	94/95	0.7	2.8	—	—	—	—	—	16	137	—	2,736	16	—	160	1,464	—	—
79	8/28	48°10'	125°33'	Vancouver	1600	78/80	1.5	5.0	—	—	—	—	—	—	—	—	—	—	—	—	6,400	—	—
80	8/29	48°13'	125°05'	Vancouver	0200	63/67	0.7	2.7	24	—	—	—	—	—	1	—	62	—	—	T	3	11	—
81	8/29	48°18'	125°25'	Vancouver	1600	74/75	1.7	5.0	11,233	—	—	—	—	—	165	—	214	115	—	—	16	1,414	6,809
82	8/30	48°21'	125°15'	Vancouver	1300	82/100	1.0	3.4	256	—	—	—	—	—	5	—	—	—	—	—	—	23	—
83	8/30	48°28'	124°54'	Vancouver	2100	95/105	0.7	2.6	184	—	—	—	—	—	35	—	3	—	—	—	—	499	1,286
84	9/11	48°21'	125°10'	Vancouver	1900	67/102	1.0	3.4	362	—	—	—	—	—	6	—	—	—	—	T	—	102	—
85	9/12	48°20'	125°11'	Vancouver	0400	41/91	1.0	3.4	132	—	—	—	—	—	3	—	—	—	—	—	—	126	48
86	9/12	48°20'	125°16'	Vancouver	1700	68/112	0.7	2.3	117	—	—	—	—	—	—	—	—	—	—	1	—	279	—
87	9/13	48°21'	125°14'	Vancouver	0200	44/101	1.5	4.9	408	—	—	—	—	—	3	—	—	—	—	—	—	456	11
88	9/13	48°16'	125°08'	Vancouver	1000	40/69	1.0	3.5	196	—	—	—	—	—	3	—	—	—	—	T	—	11	36
89	9/14	48°13'	125°08'	Vancouver	0100	51/71	0.9	3.1	161	—	—	—	—	—	139	—	6	—	—	—	—	2	4
90	9/14	48°17'	125°08'	Vancouver	1800	56/81	0.4	1.7	456	—	—	—	—	—	10	—	—	—	—	—	—	27	—
91	9/15	48°18'	125°03'	Vancouver	0300	54/98	0.6	1.7	685	—	—	—	—	—	—	—	—	—	—	—	T	143	18
92	9/15	48°09'	125°30'	Vancouver	1500	79/85	1.0	3.2	3,869	—	—	—	—	—	5	—	—	—	—	46	31	—	·311
93	9/16	48°13'	125°34'	Vancouver	0500	65/85	0.7	3.0	100	—	—	—	—	—	5	—	—	—	—	T	T	11	10
94	9/18	48°19'	125°15'	Vancouver	0300	45/98	1.0	3.3	35	—	—	—	—	—	—	—	—	—	—	—	—	16	6
95	9/18	48°26'	125°33'	Vancouver	1200	50/65	0.7	1.8	6	—	—	—	—	—	—	—	—	—	—	—	—	4	—
96	9/18	48°32'	125°21'	Vancouver	2100	50/65	1.5	4.6	514	—	—	—	—	—	134	—	—	117	—	3	T	97	—
97	9/19	48°32'	125°36'	Vancouver	0300	36/43	1.5	5.2	3,137	—	—	—	—	—	3	—	—	—	—	—	5	5	1,033
98	9/19	48°32'	126°01'	Vancouver	1000	70/75	0.2	0.4	4,433	—	—	—	—	—	—	—	—	—	—	—	—	32	—
99	9/20	48°34'	125°31'	Vancouver	0100	33/64	1.5	5.1	741	—	—	—	—	—	18	—	—	—	—	—	—	63	6
100	9/20	48°37'	125°35'	Vancouver	0500	32/71	1.5	4.2	1,859	21	—	—	—	—	—	—	—	—	—	T	—	69	9
101	9/21	48°40'	125°43'	Vancouver	0900	57/83	0.5	2.1	41	—	—	—	—	—	203	—	9	—	—	—	—	5	28
102	9/22	48°43'	125°37'	Vancouver	0400	37/60	1.5	5.0	594	—	—	—	—	—	19	—	—	—	—	2	1	7	663
103	9/22	48°48'	126°26'	Vancouver	2100	121/126	1.0	3.8	11	—	—	—	1	—	—	21	—	—	—	—	—	2	—
104	9/23	48°52'	126°11'	Vancouver	0200	54/60	1.5	5.7	89	—	—	—	—	13	43	3	—	—	—	1	—	—	—
105	9/23	49°02'	126°13'	Vancouver	1400	48/54	1.0	3.7	404	—	—	—	—	—	5	—	—	—	—	1	T	2	5
106	9/23	49°02'	126°40'	Vancouver	2100	94/98	1.1	4.1	120	—	—	—	—	43	—	—	2	230	—	1	—	—	2
107	9/24	49°06'	126°42'	Vancouver	0900	72/81	0.2	1.0	4	—	—	—	—	—	—	—	—	—	—	5	1	—	—
108	9/24	49°17'	126°28'	Vancouver	1900	77/89	0.5	1.7	—	8	—	—	—	—	T	—	—	—	—	T	T	—	—
109	9/25	49°14'	126°43'	Vancouver	0200	45/60	2.0	6.6	2	—	—	—	—	—	26	—	—	—	—	1	—	—	—
110	9/25	49°22'	126°58'	Vancouver	2100	64/74	1.6	5.6	—	—	—	—	—	—	5	—	—	—	—	T	T	—	—
111	9/26	49°21'	127°00'	Vancouver	0000	60/76	1.5	5.2	—	—	—	—	—	—	88	—	—	—	—	1	—	—	4
112	9/26	49°45'	127°22'	Vancouver	2300	46/48	0.5	1.8	—	—	—	—	—	5	32	—	—	—	—	T	T	—	—
113	9/27	48°04'	125°36'	Vancouver	1300	95/96	1.1	4.0	—	—	—	—	—	—	2	—	—	—	—	T	117	—	—
114	9/27	48°13'	125°35'	Vancouver	2300	89/90	1.0	3.3	410	—	—	—	—	—	128	—	1,242	25	—	—	—	—	—
115	9/28	48°06'	125°35'	Vancouver	0600	77/89	1.0	3.6	2	—	—	—	—	—	—	—	—	—	—	—	T	—	—
116	9/28	48°01'	125°38'	Vancouver	1000	146/151	1.0	3.4	304	—	—	—	—	—	—	13	—	—	—	—	—	18	—

Shortbelly Rockfish, *Sebastes jordani*: A Large Unfished Resource in Waters Off California

WILLIAM H. LENARZ

Introduction

The shortbelly rockfish, *Sebastes jordani*, is one of the more distinctive members of the 57 species of rockfish (genus *Sebastes*) which are reported from California waters. The species obtains its common name from the fact that its vent is about midway between the origin of the anal fin and insertion of the pelvic fin, while the vent of other species of rockfish is located farther back, much closer to the origin of the anal fin. The shortbelly rockfish also has a more strongly incised tail and a more fusiform shape than most rockfish.

Moser et al. (1977) noted that larvae of shortbelly rockfish are the longest at birth of eastern Pacific rockfish studied to date. Also, the larval period is long prior to transformation to the juvenile stage when compared with other eastern Pacific rockfish. These features, in addition to the pigmentation pattern and morphometrics of young larvae, are remarkably similar to those of the redfish or ocean perch, *S. marinus*, group of the Atlantic Ocean.

Another distinction of adult shortbelly rockfish is that it occurs in midwater and away from underwater objects such as reefs or kelp more often than most, if not all, California representatives of the genus. Occasional catches have been made by purse seiners fishing in southern California waters, and the species predominated in midwater and demersal trawl catches of rockfish off central California in the 1977 rockfish survey (Gunderson and Sample, 1980).

Shortbelly rockfish have been reported from San Benito Island, Baja California, Mexico (Moser et al., 1977) to La Perouse Bank, British Columbia (Miller and Lea, 1972). Miller and Lea also report maximum depth as 283 m (155 fathoms) and maximum total length as 305 mm (12 inches).

While there is no fishery for shortbelly rockfish, the species appears to be very abundant in California waters. Moser et al. (1977) estimated that larvae of shortbelly rockfish composed 20 percent of all rockfish larvae taken in a sampling program off southern California and 12 percent off central California in 1966. While the catch of shortbelly larvae compared with all rockfish larvae was higher off southern California than central California, the catch per standard haul was higher off central California (4.22 larvae) than southern California (2.65 larvae). The biomass in a limited area of its range, between Pt. Ano Nuevo and Pt. San Pedro, was estimated to be 295,000 metric tons (t) from the results of the hydroacoustic and midwater trawl segment of the rockfish survey) Mason[1]).

Preparation of this paper was prompted by the interest shown by both fishermen and processors in developing a fishery for shortbelly rockfish. The objectives of the paper are to summarize information on the species and: 1) Describe the biology of the species, 2) make first approximations of the reaction of the stock(s) to various levels of fishing, 3) review the rockfish survey results with regard to fishing, 4) review potential of a fishery, and 5) discuss management options for the fishery.

Biology

Larval and Juvenile Stages

Moser et al. (1977) summarized available information on larval and juvenile stages of shortbelly rockfish. The larvae are released at an average size of 5.4 mm by the ovoviviparous females between January and April. Larvae were collected between northern Baja California, Mexico, and as far north as San Francisco, Calif. Their samples were not taken north of San Francisco. While larvae were collected as far as 278 km (150 miles) offshore, all above-average catches were taken much closer to shore. They also reported that larvae metamorphose to juveniles at 27 mm and appear to begin forming schools at the surface at that time. Juveniles up to 62.8 mm have been taken by dip nets under night lights. On the other hand, specimens as small as 70 mm were taken by bottom trawling during the rockfish survey.

Growth

Shortbelly rockfish, while being one of the smaller species of rockfish, has the highest rate of growth completion (k) of 10 California species studied by Phillips (1964). The von Bertalanffy

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ABSTRACT—Shortbelly rockfish, Sebastes jordani, *appear to be abundant in California waters and present the potential for development of a new large fishery in the area. This paper contains: 1) A description of the biology of the species, 2) first approximations of the effect of fishing on the stock, 3) a review of the rockfish survey results with regard to fishing, 4) a review of the potential for development of a fishery, and 5) a discussion of management options for the fishery.*

[1]Mason, J. E. 1978. Preliminary report on the hydroacoustic/midwater trawl survey for rockfish conducted off parts of the American and Canadian west coasts during July 12-September 30, 1977. Unpubl. manuscr., 6 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

growth curve was used to describe growth:

$$L_t = L_\infty(1 - e^{-k(t-t_0)})$$

where L_t = total length (mm) at t,
t = age in years,
k = growth completion rate,
t_0 = theoretical age when fish is length 0, and
L_∞ = estimate of average length attained at maximum age.

Phillips combined age-length data from both sexes and made his estimates from back-calculated lengths (estimates of length at time of formation of each annual ring on a scale) made from scale readings and measurements. He assumed that scales form at birth. My experience with several other species of rockfish indicates that scales form when the fish reach about 20 mm. Thus the back-calculations of Phillips probably slightly under-estimate lengths of young fish.

Additional data on growth are available from the rockfish survey. Otoliths from 1,081 specimens were read. Opaque zones of fast growth were just beginning to be formed at the time of sampling (midsummer). Phillips' back-calculations appear to be at the end of the growth season (midwinter). Thus fish from the rockfish survey should be 0.5 year older than those Phillips used. Phillips used total lengths, while fork lengths were measured for the rockfish survey. Total length is about 15 mm greater than fork length for shortbelly rockfish, and the survey data were adjusted accordingly. The program BGC2 (Abramson, 1971) was used to estimate parameters of the growth curve. The estimate of k for the survey data, 0.27721, is very close to the estimate by Phillips, 0.27520. The estimates of L_∞ are also close, 315 (Phillips) and 301 (survey). Comparison of the two growth curves (Fig. 1) reveals that the main differences occur at young ages. As previously mentioned, Phillips probably underestimated length of fish at young ages. Also

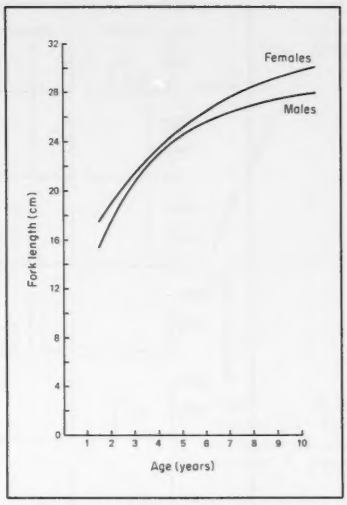

Figure 1.—Von Bertalanffy growth curves for *Sebastes jordani* estimated from this study and by Phillips (1964).

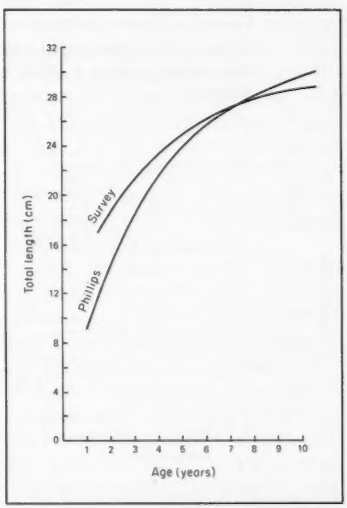

Figure 2.—Von Bertalanffy growth curves for female and male *Sebastes jordani*. L_∞ is 324 mm for females and 290 mm for males; k is 0.2112 for females and 0.2980 for males.

mesh size of the nets used by the survey may have selected for relatively large fish at young ages. Phillips obtained fish from several sources and evaluation of selectivity is not possible. Data from the surveys (Fig. 2) indicated that females grow larger than males and attain maximum size at a slower rate of completion (lower k). Growth does not appear to be related to depth of capture, but there are insufficient data from the survey to arrive at conclusive results.

Length-Weight

The length-weight relationship was estimated by Phillips to be $\log W = \alpha + \beta \log L$, where W = weight in pounds, L = total length (mm), $\alpha = -8.05202$, and $\beta = 3.1518$.

Maturation, Fecundity, and Sex Composition

Phillips (1964) reported that 50 percent of shortbelly rockfish " . . . are mature when 6½ inches [16.5 cm] long, or 3 years old." The fecundity-length relationship, estimated by me from Phillips' data on 10 specimens is $\ln F = \alpha + \beta \ln L$, where F = fecundity (numbers of eggs), L = total length (mm), $\alpha = -8.43523$, and $\beta = 3.30611$.

About 45 percent of the survey catches of shortbelly rockfish between 14 cm and 27 cm were males. Few of the fish larger than 27 cm were males.

Movements

While many aspects of the life history of shortbelly rockfish appear in the literature, nothing could be found on movements. Tagging studies on blue rockfish, *S. mystinus*, Miller and Geibel (1973); yellowtail rockfish, *S. flavidus*, Carlson and Haight (1972); copper rockfish, *S. caurinus*, Dewees (1970); and black-and-yellow rockfish, *S. chrysomelas*, and gopher rockfish, *S. carnatus*, Hallacher (1977) and Larson (1977) indicated little movement. However, these five species do not have strongly incised tails or fusiform bodies. These aspects of morphology would suggest that shortbelly rockfish are stronger swimmers and are better adapted to swim away from predators and/or make more extensive movements than the other five species (Hobson and Chess, 1978). Analyses of catch rates of Pacific ocean perch, *S.*

alutus, indicate considerable movement into relatively shallow waters during spring and summer and return to deeper water in the winter (Gunderson, 1972). Pacific ocean perch have more strongly indented tails and fusiform bodies than the five species that were tagged but less than shortbelly rockfish. Sorokin (1961) documented long (at least 1,112-km (600-mile)) migrations of stocks of redfish (or ocean perch), and deep-water redfish, *S. mentella*, in the Atlantic Ocean.

Data from bottom trawl catches of the rockfish survey indicate that shortbelly rockfish do make significant movements. Length and age samples were expanded to entire catches assuming that sampled fish were taken at random. Size of fish tends to increase with depth (Fig. 3). Size for a given depth stratum tends to increase in a northerly direction between lat. 34° and 39°N. Depth of capture of shortbelly rockfish also tends to increase in a northerly direction between lat. 35° and 39°N. The combined results of these trends is a very strong tendency for size to increase in a northerly direction between lat. 34° and 39°N (Fig. 4). While age composition data are not sufficient to separate effects of depth and latitude, age of shortbelly rockfish tends to increase as depth and latitude increase (Fig. 5). The age and length composition data from the rockfish survey indicate that at least during summer, shortbelly rockfish tend to move into deeper waters and to the north as they grow.

Data on larvae revealed areas of heavy spawning from Los Angeles to at least San Francisco during January 1966 and March 1975.[2] Very heavy spawning occurred off Monterey (lat. 37°N), Avila Beach (lat. 35°N), and Santa Barbara (lat. 34°N). Heaviest spawning occurred off Monterey. The heavy spawning from Los Angeles to at least San Francisco in the same month indicated that if shortbelly rockfish do tend to move north as they grow, they do not make long return migrations to the south in the winter to spawn.

[2]Unpublished data of H. G. Moser, Southwest Fisheries Center, NMFS, NOAA, P.O. Box 271, La Jolla, CA 92038. Pers. commun. 1978.

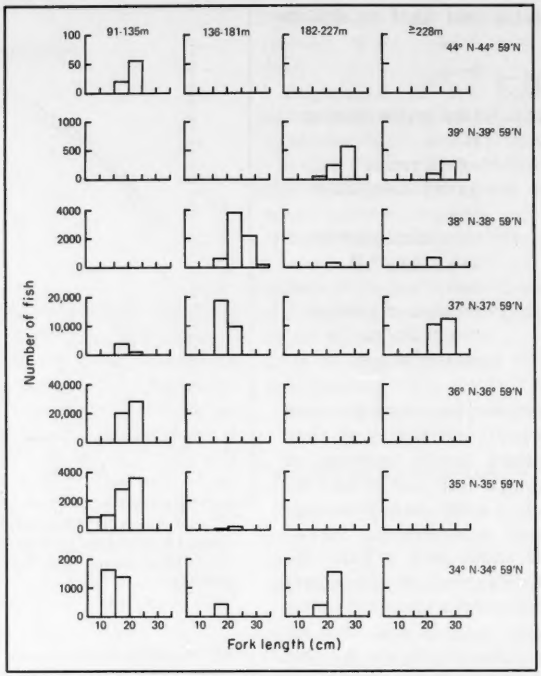

Figure 3.—Length composition of *Sebastes jordani* caught by bottom trawling during rockfish survey as a function of depth and latitude.

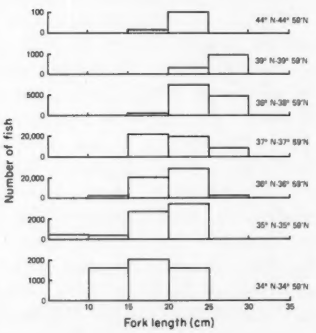

Figure 4.—Length composition of *Sebastes jordani* caught by bottom trawling during rockfish survey as a function of latitude.

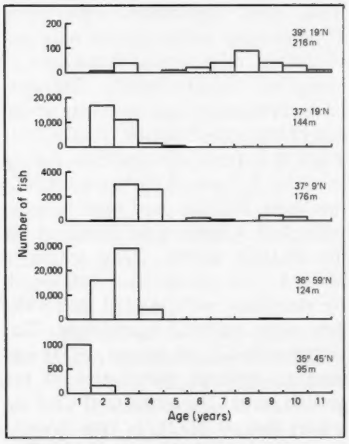

Figure 5.—Age composition of bottom trawl catches of *Sebastes jordani* during rockfish survey.

Relationships With Other Species

Shortbelly rockfish appear to be an important prey item in central and southern California. Merkel (1957) found that rockfish represented 22.5 percent of the food volume of chinook

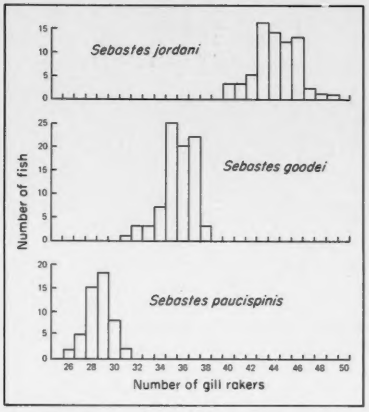

Figure 6.—Gill raker frequencies of *Sebastes jordani*, *S. goodei*, and *S. paucispinis*.

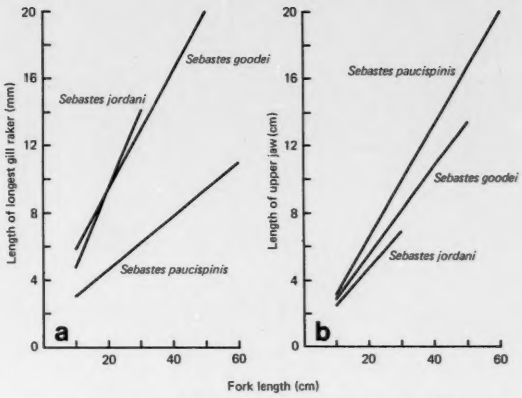

Figure 7.—Relationships between length of longest gill raker and fork length (a) and length of upper jaw and fork length (b) for *Sebastes jordani*, *S. goodei*, and *S. paucispinis*.

salmon, *Oncorhynchus tshawytscha*, off San Francisco between February and November. In June and July more than 50 percent of the food was rockfish, of which 70 percent was shortbelly rockfish. Few of the rockfish exceeded 89 mm (3.5 inches). Shortbelly rockfish less than 89 mm are probably in their first year of life. Of 78 fish sampled from pigeon guillemots, *Cephus columbia*, nesting on the Farallon Islands, two were shortbelly rockfish that were 59 and 83 mm in standard length (Follet and Ainley, 1976). Hubbs et al. (1970) reported that 4 otoliths of shortbelly rockfish were found in 498 otoliths sampled from western gull, *Larus occidentalis*, castings near San Diego. The fish were thought to have been stolen from Brandt's cormorant, *Phalacrocorax penicillatus*. Trawl-caught bocaccio, *S. paucispinis*, and chilipepper, *S. goodei*, are often seen with shortbelly rockfish protruding from their mouths, but these specimens may represent unnatural feeding within the trawl. A number of studies on food of fish, marine mammals, and birds found small rockfish to be important prey items, but did not identify the items to species. In summary, at times shortbelly rockfish can be an important prey item for chinook salmon and possibly other fish. They also compose yet undetermined portions of the diets of some birds. Only two studies reported the size of consumed shortbelly rockfish. In both cases small fish, probably less than 1 year old, predominated.

Shortbelly rockfish belong to a group of important rockfish that inhabit California waters between 50 and 125 fathoms (91 and 229 m) during adult life. The other two members are bocaccio and chilipepper, both of which are very important components of California rockfish landings. All three species are relatively fusiform and have deeply incised tails for rockfish.

Since the three species are often caught together and belong to the same genus, ecological theory requires that there be mechanisms that separate the species into different niches. Morphological features, measured following procedures of Phillips (1957), related to feeding differ considerably among the species. For example, there is almost no overlap in gill raker counts for the three species (Fig. 6). However, the relationship between length of the largest gill raker of the first arch and fork length is similar for chilipepper and shortbelly rockfish, but differs between these two species and bocaccio (Fig. 7a). There are considerable differences in the relative length of upper jaw among the species (Fig. 7b). The data presented in Figures 6 and 7 suggest that shortbelly rockfish consume the smallest organisms, probably plankton, of the three species and bocaccio consume the largest, probably fish. Phillips (1964) stated that the shortbelly rockfish " . . . feed exclusively on macroplanktonic organisms, primarily euphausids," while chilipepper " . . . may feed on euphausids and small squids, or on small fishes such as anchovies, young hake, *Merluccius productus*, and lanternfish," and bocaccio " . . . feed on smaller rockfishes, sablefish, *Anoplopoma fimbria*, anchovies, lantern-fish, and squids, *Loligo opalescens*."

A compilation of upper jaw length frequencies of the three species in rockfish survey tows containing shortbelly rockfish indicates little overlap (Fig. 8). Since young specimens of the larger species have jaw lengths of the same size as older specimens of the smaller species, the lack of overlap shown in Figure 8 suggests that the three species are distributed in a fashion that minimizes the possibility of competition for food.

First Approximation of Reaction of Species to Fishing

Yield per recruit calculations often are used to make first approximations of production of a stock under different fishing strategies. Estimates of growth

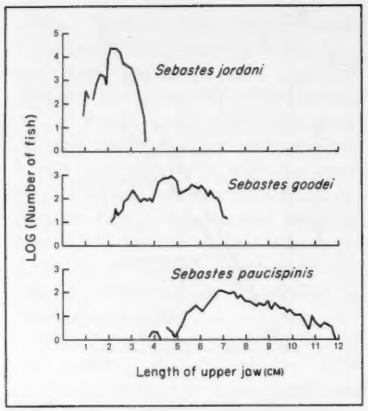

Figure 8.—Frequencies of upper jaw length of *Sebastes jordani*, *S. goodei*, and *S. paucispinis* caught in rockfish survey bottom trawls containing *S. jordani*.

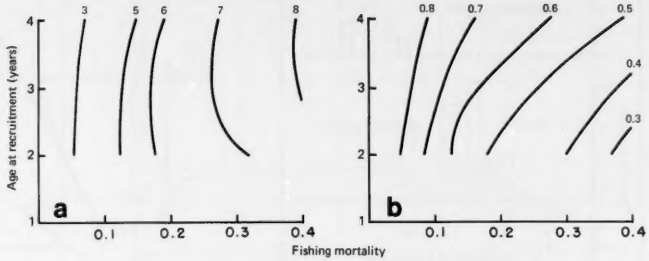

Figure 9.—Yield per recruit (a) and relative fecundity (b) (production of larvae by fished stock/production of larvae by unfished stock) of *Sebastes jordani* as functions of age at recruitment and instantaneous rate of fishing mortality (F).

and mortality are needed for the calculations. Growth estimates have already been presented. No estimates of mortality rates were found in the literature. Often the rate of natural mortality (M) is approximately equal to k (Beverton and Holt, 1959). Thus a first approximation of M is 0.275. Of 1,081 shortbelly rockfish aged from rockfish survey catches the oldest were 12 years old, which is older than the 10-year maximum age reported by Phillips (1964). It is likely that, if M is significantly lower than 0.275, older fish would occur in the samples. Indeed, a higher value of M would be reasonable.

Assuming that natural mortality is constant and that fishing mortality is constant beyond age at recruitment, I used the Ricker (1958) yield equation to estimate yield per recruit at three ages of recruitment: 2, 3, and 4 years. Results of the calculations indicate that yield per recruit is not sensitive to age of recruitment at F (fishing mortality) values less than 0.25 (Fig. 9a). When F is greater than 0.25, yield per recruit for recruitment at ages 3 or 4 is greater than when age at recruitment is 2 years. There is little difference in yield per recruit when age at recruitment is 3 or 4 for the values of F between 0.05 and 0.4.

The fecundity of shortbelly rockfish is similar to the clupeids which have a well-documented history of recruitment failures in heavily fished stocks (Murphy, 1977). With this in mind, the effect of fishing on production of larvae by a population of shortbelly rockfish was estimated. Fish were assumed to spawn once at the beginning of the year, the maturity schedule and fecundity-age relationship described in the Biology section were used, and fishing rates were assumed to be equal for males and females. The results (Fig. 9b) indicated that fishing would have a considerable effect on relative fecundity (production of larvae of fished stock/production of larvae of unfished stocks), and that relative fecundity is very sensitive to age at recruitment at higher levels of fishing mortality.

Review of Rockfish Survey Results With Regard To Fishing

Numbers of catches of shortbelly rockfish exceeding 450 kg (1,000 pounds) were made by 0.5-hour bottom and midwater trawls during the rockfish survey and a pilot survey (Gunderson and Nelson[3]) in the Monterey area during 1976 (Table 1). An area of high catches by both gears in both years was between lat. 36°56′ and 37°21′N. Large catches were made by both gears between lat. 36°18′ and 36°30′N in 1976 but not in 1977 even though nine bottom trawl hauls were made in the area in 1977. Most large midwater catches were taken by trawling close to the bottom. The midwater trawl catches averaged higher than the bottom trawl catches, 3,728 and 1,952 kg, respectively, probably because bottom trawls were set at preselected stations, while

[3]Gunderson, D., and M. Nelson. 1977. Preliminary report on an experimental rockfish survey conducted off Monterey, California, and in Queen Charlotte Sound, British Columbia, during August-September 1976. Unpubl. manuscr., 82 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Table 1.—Catches of shortbelly rockfish, *Sebastes jordani*, that exceeded 450 kg in one-half hour bottom and midwater trawls during 1977 rockfish survey and 1976 pilot survey.

Date	Position at beginning of tow		Depth (m)		Catch (kg)
	Lat. (N)	Long. (W)	Gear	Bottom	
Bottom trawls					
8-15-76	36°42′	121°58′	101	101	459
8-19-76	36°20′	122°3′	212	212	627
8-19-76	36°30′	122°0′	177	177	4,120
7-18-77	35°33′	121°12′	132	132	519
7-27-77	36°59′	122°22′	124	124	4,722
7-27-77	37°10′	122°43′	176	176	881
7-30-77	37°19′	122°50′	144	144	2,790
7-30-77	37°18′	122°53′	240	240	2,499
8-4-77	38°21′	123°25′	144	144	954
Midwater trawls					
8-12-76	36°56′	122°20′	154	229	3,314
8-13-76	37°11′	123°48′	302	302	3,156
8-13-76	37°12′	122°50′	282	285	1,415
8-19-76	36°18′	122°3′	161	165	3,313
8-20-76	36°27′	122°0′	274	274	7,264
7-27-77	37°13′	122°48′	245	247	4,055
7-27-77	37°21′	122°52′	188	192	3,578

midwater trawling was directed at concentrations detected through echo sounding.

Aimed midwater trawling could prove to be an efficient method of harvesting shortbelly rockfish which form large, off-bottom schools which are readily detected by echo sounding. The survey work indicated that with relatively little experience fishermen could learn to distinguish shortbelly rockfish from other abundant schooling species such as Pacific whiting which is the species most likely to contribute to unwanted by-catches.

Because of the small size of shortbelly rockfish, trawls would have to be constructed of mesh size smaller than allowed for bottom trawls by California regulations, 4.5 inches (11.43 cm). Cod ends used in the rockfish survey were constructed of 1.25-inch (3.18 cm) webbing. Mesh size experiments are required to determine optimum size for shortbelly rockfish.

The present California regulations are designed to prevent capture of flatfish and other rockfish that are smaller than desired. Thus by-catches of other fish should be considered. In the belief that fishermen targeting on shortbelly rockfish would limit their effort to areas producing large catches of shortbelly rockfish, catch compositions of hauls that produced more than 450 kg of shortbelly rockfish were compiled for bottom and midwater trawls made during the rockfish and pilot surveys.

The catch by weight of species other than shortbelly rockfish was considerably higher for bottom trawling (23.67 percent) than for midwater trawling (3.04 percent). Most of the by-catch was Pacific whiting for midwater trawling, while the by-catch for bottom trawling was dominated by chilipepper; bocaccio; Pacific whiting; jack mackerel, *Trachurus symmetricus*; and spiny dogfish, *Squalus acanthias*. Only 0.54 percent of the midwater trawl catches were composed of target species of domestic fishermen: Chilipepper, bocaccio, and sablefish. A relatively high 10.39 percent of the bottom trawl catches were composed of target species: Chilipepper; bocaccio; darkblotched rockfish, *S. crameri*, Dover sole, *Microstomus pacificus*; rex sole, *Glyptocephalus zachirus*; and jack mackerel.

The by-catch in a shortbelly rockfish fishery evidently can be kept at low levels by using only midwater trawls, but it would also be desirable to control age at recruitment. If mesh size restrictions prove impractical in accomplishing this, the relationships between size and age composition with depth and area of bottom trawl hauls indicated that fishermen may be able to minimize catches of relatively small or young shortbelly rockfish by choice of depth and area fished (Fig. 3, 4). Similar relationships are apparent between depth of haul and length compositions of large catches of shortbelly rockfish made by midwater trawls. Five out of nine large catches were made at depths exceeding 182 m (99.5 fathoms), and fish smaller than 200 mm fork length were not caught in significant numbers at these depths. Thus it appears that, at least during summer, fishermen may be able to minimize catches of small shortbelly rockfish through choice of depth fished. If mesh size restrictions prove practical, it appears that catches would be maximized by fishing at relatively deep depths.

Potential for Development of the Fishery

S. Kato, a fishery biologist specializing in fisheries development at the Tiburon Laboratory of the NMFS Southwest Fisheries Center, has identified several potential markets for shortbelly rockfish. There may be a small export market for good quality whole frozen fish. Another possible use is canning for either pet or human consumption, and a small test pack found the product acceptable as pet food. A possibly very large market exists for use as a raw product for surimi. The flesh appears to be of suitable quality for surimi, but their small size may make shortbelly rockfish more expensive to process than species currently used. Kato has tentatively estimated that the price to fishermen would be about $100 to $200 per ton. Actual prices, of course, will depend on a number of economic factors that can only be evaluated by fishermen and processors, and negotiations between the two parties.

High catch rates are necessary to support a fishery for a species that has a price range between $100 and $200 per ton. It would probably be necessary for a vessel to capture 10 to 20 tons per day to exceed operating costs. In addition to operating costs, capital outlays would be necessary to equip bottom trawlers for midwater trawling.

While the potential market, large biomass, and large catches shown in Table 1 indicated that there is considerable potential for development of a fishery for shortbelly rockfish, assistance by government agencies may be necessary for fullfillment of the potential. Kato has begun the development process by locating potential markets, purchasing appropriate fishing gear, and working with fishermen and processors in initiating a test fishery.

Management Options For Fishery Development

Management (State of California, Pacific Fishery Management Council, and U.S. Department of Commerce) has the option of either allowing or not allowing a fishery for shortbelly rockfish to develop. An argument against development of a fishery is that shortbelly rockfish have been shown to be prey items for important species such as chinook salmon (Merkel, 1957). On the other hand, Merkel's study showed that while shortbelly rockfish composed about 16 percent of the food of chinook salmon, 51 percent of the food was composed of northern anchovy, *Engraulis mordax*, Pacific herring, *Clupea harengus pallasi*, and squid (mostly *Loligo opalescens*). Significant fisheries have existed on these species without any documented evidence of causing feeding problems for chinook salmon. In addition Merkel estimated that euphausids composed 15

percent of the food of chinook salmon. Since shortbelly rockfish mainly feed on euphausids (Phillips, 1964), they may compete with chinook salmon.

Management also has the option of placing restrictions on types of gear, seasons, and locations. The results of this study suggest that it may be advisable to allow the use of midwater trawls but not bottom trawls because of relatively large by-catches of species other than shortbelly rockfish when bottom trawls are used. While yield per recruit and population fecundity analyses indicated that age at recruitment should probably be 3 or 4 years if a significant fishery develops, information is not available to make specific recommendations on obtaining that age at recruitment. The data (available only for summer months) indicated that fishermen may be able to avoid capture of small fish by choice of fishing depths and locations. No data are available on the practicality of using mesh size restrictions as a means to obtain a desired size at recruitment. Mesh size experiments and test fishing are required to determine the correct policy for obtaining a specific size at recruitment.

Estimates of a large biomass of shortbelly rockfish (295,000 t in a small portion of its range) indicated that the population could support a large fishery. However, the relatively low fecundity of the species suggests that caution in developing the fishery would be prudent. A relatively small fishery, e.g., 5,000-10,000 t of fish, may be desirable until more is known about the species. A small test fishery would allow development of procedures to obtain desired size at recruitment through mesh size experiments and monitoring of size and age composition of the catch with respect to depth and area of catch. Location and extent of areas containing high densities of fish would provide more information on size of the stock(s). Further analyses of larval survey data may provide additional estimates of stock size. Hydroacoustic midwater trawl surveys probably could be designed to produce estimates of stock size in areas of high densities of the species at relatively low cost. If the above data indicate the possibility of more than one important stock, appropriate studies should be carried out to determine the stock structure. Finally, additional work, such as predator-prey studies, on the position of shortbelly rockfish in the community is desirable. Ideally, management should take into account the effect of fishing on shortbelly rockfish on both its predators and competitors. However, as is the case for other marine fisheries, little is known on the interactions of shortbelly rockfish with other species.

Acknowledgments

Much of the data used for this report was collected by the 1977 rockfish survey and the 1976 pilot survey. The efforts of the skippers, crews, and scientific parties of the vessels *John N. Cobb, Commando, Miller Freeman, David Starr Jordan, Pat San Marie,* and *Pacific Raider* are appreciated.

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Literature Cited

Abramson, N. J. 1971. Computer programs for fish stock assessment. FAO Fish. Tech. Pap. 101, var. pag.

Beverton, R. J. H., and S. J. Holt. 1959. A review of the life spans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. *In* G. E. W. Wolstenholme and M. O. Conner (editors), Ciba Foundation colloquia on ageing, Vol. 5. The lifespan of animals, p. 142-177. Little, Brown, Boston.

Carlson, H. R., and R. E. Haight. 1972. Evidence for a home site and homing of adult yellowtail rockfish, *Sebastes flavidus*. J. Fish. Res. Board Can. 29:1011-1014.

Dewees, C. M. 1970. Population dynamics and fishing success of an artificial reef in Humboldt Bay, California. M.S. Thesis, Humboldt State Univ., Arcata, Calif., 77 p.

Follet, W. I., and D. G. Ainley. 1976. Fishes collected by pigeon guillemots, *Cephus columba* (Pallas), nesting on southeast Farallon Island, California. Calif. Fish Game 62:28-31.

Gunderson, D. R. 1972. Evidence that Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound form aggregations that have different biological characteristics. J. Fish. Res. Board Can. 29:1061-1070.

Gunderson, D. R., and T. M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev. 42(3-4):2-16.

Hallacher, L. E. 1977. Patterns of space and food use by inshore rockfishes (Scorpaenidae: *Sebastes*) of Carmel Bay, California. Ph.D. Thesis, Univ. Calif., Berkeley, 115 p.

Hobson, E. S., and J. R. Chess. 1978. Trophic relationships among fishes and plankton in the lagoon at Enewetak Atoll, Marshall Islands. Fish. Bull., U. S. 76:133-153.

Hubbs, C. L., A. L. Kelly, and C. Limbaugh. 1970. Diversity in feeding by Brandt's cormorant near San Diego. Calif. Fish Game 56:156-165.

Larson, R. J. 1977. Habitat selection and territorial competition as the causes of bathymetric segregation of sibling rockfishes (*Sebastes*). Ph.D. Thesis, Univ. Calif., Santa Barbara, 170 p.

Merkel, T. J. 1957. Food habits of the king salmon *Onchorhynchus tshawytscha* (Walbaum), in the vicinity of San Francisco, California. Calif. Fish Game 43:249-270.

Miller, D. J., and J. J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Calif. Dep. Fish Game, Fish Bull. 158, 137 p.

———, and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game, Fish Bull. 157, 235 p.

Moser, H. G., E. H. Ahlstrom, and E. M. Sandknop. 1977. Guide to the identification of scorpionfish larvae (family Scorpaenidae) in the eastern Pacific with comparative notes on species of *Sebastes* and *Helicolenus* from other oceans. U. S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 402, 71 p.

Murphy, G. I. 1977. Clupeoids. *In* J. A. Gulland (editor), Fish population dynamics, p. 283-308. John Wiley & Sons, N.Y.

Phillips, J. B. 1957. A review of the rockfishes of California (family Scorpaenidae). Calif. Dep. Fish Game, Fish Bull. 104, 158 p.

———. 1964. Life history studies on ten species of rockfish, (genus *Sebastodes*). Calif. Dep. Fish Game, Fish Bull. 126, 70 p.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Board Can., Bull. 119, 300 p.

Sorokin, V. P. 1961. The redfish; gametogenesis and migrations of the *Sebastes marinus* (L.) and *Sebastes mentella* Travin. Rapp. P.-V. Réun. Cons. Int. Explor. Mer 150:245-250.

Abundance, Size and Age Composition, and Growth of Pacific Ocean Perch, *Sebastes alutus*, Sampled During 1977

JAMES T. GOLDEN, ROBERT L. DEMORY, and WILLIAM H. BARSS

ABSTRACT–The 1977 rockfish survey provided the first opportunity for a detailed examination of Pacific ocean perch, Sebastes alutus, *stocks inhabiting waters off the coasts of California, Oregon, and Washington. From catch data, estimates of biomass, age and size composition were determined. Estimates of marketable biomass (≥30 cm) were 175 t in the INPFC Eureka area, 6,467 t in the Columbia area, and 7,685 t in the southern portion of the Vancouver area. The Columbia area estimate is well below that of the 1966-68 period but substantially greater than the estimate for the 1973-74 period. The 1970 year class dominated catches of Pacific ocean perch in most strata sampled. They were particularly abundant in the 100-149 fathom (183-272 m) depth strata. There were marked differences in age composition from south to north in the Columbia and Vancouver areas. Older fish were more abundant in the northern one-third of the Columbia area and throughout the Vancouver area. Statistical comparison of growth rates between the Columbia and Vancouver areas showed no significant difference in growth rate.*

Introduction

Marine resource surveys provide measures of abundance and size and age composition of rockfish that are independent of commercial landing data. This report contains a summary of analysis of data obtained on Pacific ocean perch, *Sebastes alutus*, from the 1977 coastwide rockfish survey. Because of the large number of species involved and the discontinuous distribution of major species within the geographic range of the survey, data analysis responsibilities were divided among the participating agencies. The Oregon Department of Fish and Wildlife (ODFW) elected to analyze data collected from Pacific ocean perch because it has a particular interest in this species, both in terms of stock assessment and the commercial fishery. The ODFW routinely samples commercial landings of Pacific ocean perch for age, size, sex, and maturity, and the survey provided a means of obtaining additional biological data on this species. The survey also provided the opportunity to sample deep water (>150 fathoms or 274 m) segments of perch stocks only lightly fished by the commercial fishery.

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Methods

Catch Composition

Commercial landings of perch-like species (those hailed as nominal perch by commercial fishermen) must be interpreted using catch composition samples to determine the landings of Pacific ocean perch. The proportion of Pacific ocean perch (by weight) in all rockfish as well as other perch-like rockfish caught during the 1977 rockfish survey was determined for each 30′ interval from Cape Blanco (lat. 42°30′ N) north to Cape Flattery (lat. 48°30′ N). Perch-like species that were included in the calculations were darkblotched rockfish, *S. crameri*; splitnose rockfish, *S. diploproa*; redstripe rockfish, *S. proriger*; yellowmouth rockfish, *S. reedi*; stripetail rockfish, *S. saxicola*; and sharpchin rockfish, *S. zacentrus*. Only tows made at depths greater than 100 fathoms (183 m) were used in calculating the proportions for both indices.

Biomass

Biomass estimates (metric tons) of Pacific ocean perch were determined as outlined by Gunderson and Sample (1980), for International North Pacific Fisheries Commission (INPFC) Eureka, Columbia, and Vancouver statistical areas. Since the survey estimates included small fish (<30 cm) that are not suitable for market use, biomass estimates were adjusted downward so that they would be useful in comparison with biomass estimates derived from commercial catch per unit effort (CPUE) data (CPUE in t/hour). To accomplish this, a length-weight key was used to determine the weight of fish smaller than 30 cm, which was subsequently subtracted from the survey estimate. Biomass estimates based on commercial CPUE for the INPFC Columbia area were determined by dividing the total area available to the fleet (717 square miles) by the area swept by the trawl in 1 hour and multiplying the quotient by the average commercial CPUE. This method is based on an assumed towing speed of 2.5 knots with a horizontal trawl opening of 35 feet. Commercial biomass estimates were not stratified by depth or geographic area.

Age and Size Composition

Age and size composition samples were collected for Pacific ocean perch using the sampling scheme described by Gunderson and Sample (1980) at the latitudes and depth intervals within INPFC areas listed in Table 1. Samples were not available for all depths in some of the normal sampling density areas (tracklines spaced every 10 nautical miles). This was due in part to the low abundance of Pacific ocean perch at 50 to 99 fathoms (91-181 m).

The ages of the individuals sampled were determined by counting the translucent winter growth bands on the

otoliths following the method described by Westrheim (1973).

Age and length frequency samples for individual tows were weighted to the total catch from which the samples were taken. The expanded age or length compositions (sexes combined) were then combined within area and 50-fathom depth strata for each INPFC area, and further expanded to the total estimated population.

Growth

Individual length observations weighted to the raw age composition of Pacific ocean perch were fitted to the von Bertalanffy growth in length curve following the procedure used by Tomlinson and Abramson (1961). Growth rates by sex were compared between 100-149 fathom (183-272 m) and 150-199 fathom (274-364 m) depth intervals within INPFC Columbia and Vancouver areas. Growth rates were then compared between INPFC areas after pooling the age composition for all depth intervals (i.e., 100-199 fathoms). Perch from 6 to 18 years of age were used in making estimates of L_{∞}, k, and t_0.

Results

Catch Composition

Pacific ocean perch represented 22.7 to 73.8 percent of the total weight of rockfish caught between Cape Blanco and Cape Flattery with the proportion of perch caught increasing with latitude. Similarly, Pacific ocean perch ranged from 30.7 to 83.7 percent of the weight of associated perch-like species (Fig. 1). Of the perch-like species (other than the Pacific ocean perch), the most important contributors to the catch composition were splitnose rockfish (9.1 percent), sharpchin rockfish (8.2 percent), and darkblotched rockfish (8.1 percent). Of non-perch-like species, shortspine thornyhead, *Sebastolobus alascanus* (8.2 percent), yellowtail rockfish, *S. flavidus* (4.6 percent), and rougheye rockfish, *S. aleutianus* (4.3 percent), were important in making up the catch of total rockfish. Pacific ocean perch represented 16.2, 62.3, and 92.3 percent of perch-like species in commercial landings in Pacific Marine Fisheries Commission (PMFC) areas 2B (lat. 42°50′-44°18′N), 2C (lat. 44°18′-45°46′N), and 3A (lat. 45°46′-47°20′N), respectively.

Table 1.—Numbers of Pacific ocean perch sampled for age and length composition at different latitudes and depth intervals within INPFC Eureka, Columbia, and Vancouver areas during the 1977 rockfish survey (number of otoliths read is shown in parentheses).

INPFC area	Sampling density type[1]	Latitude (N)	Depth interval (fathoms) 50-99		100-149		150-199		200-260	
Eureka	N	40°26′-43°	0	(0)	81	(0)	132	(0)	0	(0)
Columbia	N	43°-45°	0	(0)	439	(155)	247	(112)	6	(0)
	H	45°-46°44′	307	(190)	1,741	(982)	664	(304)	259	(23)
	N	46°44′-47°30′	0	(0)	283	[2](72)	270	[2](0)	131	(0)
Vancouver	N	47°30′-47°50′	0	(0)	130	(129)	0	(0)	0	(0)
	H	47°50′48°30′	70	(70)	1,040	[2](539)	383	(262)	136	(135)

[1]N=tracklines 10 nmi apart; H=tracklines 5 nmi apart.
[2]In INPFC Columbia area from lat. 46°44′ to 47°30′N, 126 and 67 otoliths from 100-149 and 150-199 fathoms, respectively, were unusable, and were not included in the totals in parentheses. Similarly, in INPFC Vancouver area from lat. 47°50′ to 48°30′N at 100-149 fathoms, 93 otoliths were unusable.

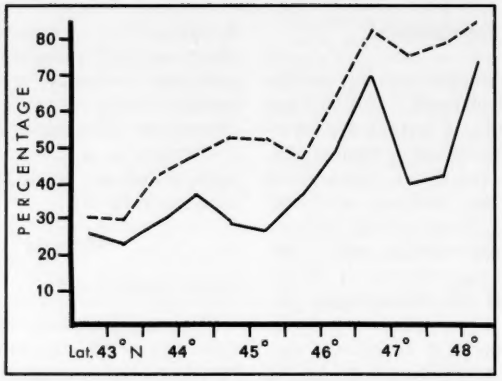

Figure 1.—The percentage of Pacific ocean perch in survey catches of rockfish (solid line) and perch-like rockfish (dashed line) by 30′ intervals of latitude from south to north.

Biomass

Estimated biomass based on the survey data is shown in Table 2. In the Columbia area, the estimate of biomass based on CPUE of the commercial catch was 9,600 t.

Although the survey estimate is 33 percent less than the estimate based on commercial CPUE data, this is to be expected as a consequence of the fact that commercial trawlers bias their fishing towards areas of high local abundance. Both estimates showed an increase in stock biomass relative to the 1973-74 estimate reported by Gunderson et al. (1977) but remained well below the estimated biomass of 35,000 t reported during the 1966-68 period (Westrheim et al., 1972).

Table 2.—Biomass estimates, 95 percent confidence intervals, 1977 landings, and estimated exploitation rate. Numbers in parentheses are adjusted biomass estimates of marketable fish ≥30 cm.

INPFC area	Biomass (t)	95% C.E. (±%)	1977 landings	Exploitation rate
Monterey	2	±82	—	—
Eureka	223 (175)	±76	65	0.29
Columbia	7,105 (6,467)	±49	[1]479	0.07
Vancouver	7,728 (7,685)	±136	817	0.11

[1]Includes foreign catch.

Age and Size Composition

The presence of a strong 1970 year class was evident in depths from 50 to 199 fathoms (91-364 m) in the Columbia area (Fig. 2, 3). Secondary modes occurred at 13-14 years from lat. 43°00′ to 45°00′ N and at 10-16 years from lat. 45°00′ to 46°44′ N with the 1970 year class being absent at depths greater than 200 fathoms (366 m). A single sample from lat. 46°44′ to 47°30′ N indicated the presence of fish 11 years and older in the 100-149 fathom (183-272 m) zone (Fig. 4). Another sample from the region immediately to the north (lat. 47°30′-47°50′ N) once again showed the dominance of the 1970 year class in the 100-149 fathom depth interval, however (Fig. 4).

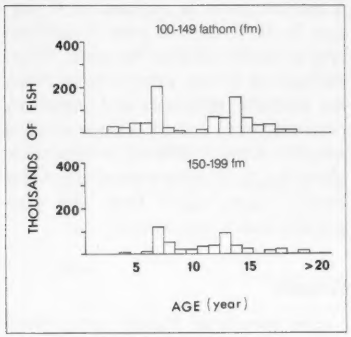

Figure 2.—Age composition of Pacific ocean perch in the southern portion of the INPFC Columbia area (lat. 43°00′-45°00′N), expanded to the total population.

Due to the presence of a large catch of Pacific ocean perch that was not sampled for otoliths in the area bounded by lat. 47°51′-48°30′ N, the age composition for the 100-149 fathom interval was estimated using an age-length key derived from other samples taken in the same area. Although the 1970 year class is still obvious, it was far overshadowed by the presence of older, larger fish. The 1970 year class was present, but not dominant, in 150-199 fathoms (274-364 m) and was absent in depths greater than 200 fathoms (Fig. 5).

After adjusting the age composition to the total population estimate within each depth zone and geographic area, the data for all strata were combined and expanded to the total population for each INPFC area. The 1970 year class was dominant in the Columbia area and obvious but not dominant in the Vancouver area (Fig. 6). The modal age was 19 years in the Vancouver area. Secondary modes within the two areas occurred at 13 and 14 years, respectively.

In addition to survey age data from the Columbia area, age composition data from commercial landings were also available for comparison. Survey age composition showed a greater abundance of older fish because the survey included samples from depths greater than those which are normally fished by the fleet in the summer (Fig. 7). In addition, the depleted state of older fish combined with the presence of the strong 1970 year class have contributed to a concentration of effort by the fleet in areas of local high abundance (i.e., in shallower water).

Length frequency data for Pacific ocean perch were compiled for combined sexes and were expanded to the total population for each stratum where

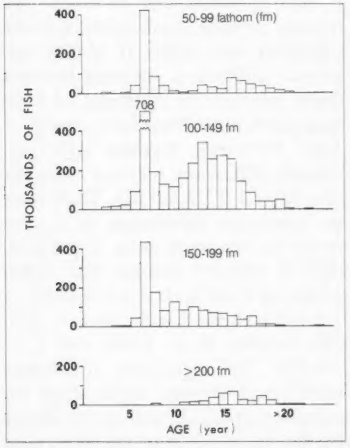

Figure 3.—Age composition of Pacific ocean perch in the middle portion of the INPFC Columbia area (lat. 45°00′-46°44′ N), expanded to the total population.

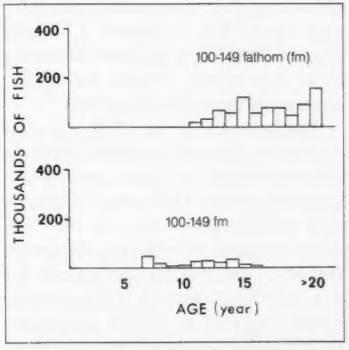

Figure 4.—Age composition of Pacific ocean perch in the northernmost portion of the INPFC Columbia area (lat. 46°44′-47°30′N) (top) and the southernmost portion of the INPFC Vancouver area (lat. 47°30′-47°50′N) (bottom), expanded to the total population.

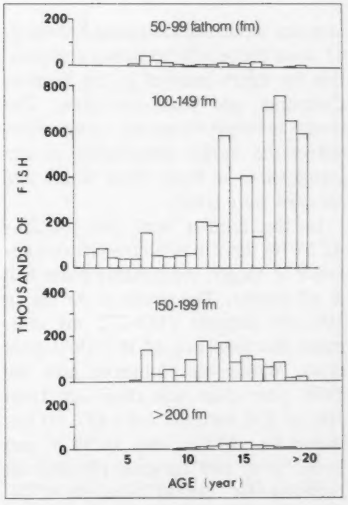

Figure 5.—Age composition of Pacific ocean perch in the middle portion of the Vancouver area (lat. 47°51′-48°30′N), expanded to the total population.

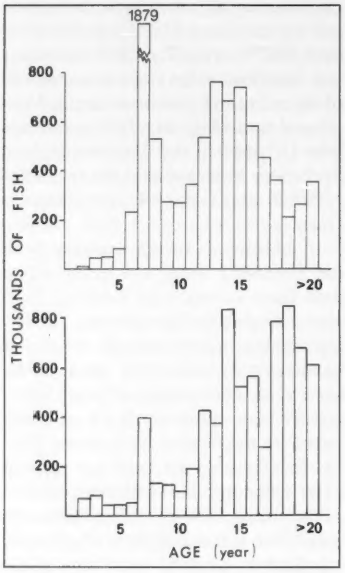

Figure 6.—Age composition of Pacific ocean perch in INPFC Columbia (lat. 43°00′-47°30′N) (top) and Vancouver (lat. 47°30′-48° 30′N) (bottom) areas, all depth intervals combined. Samples expanded to the total population.

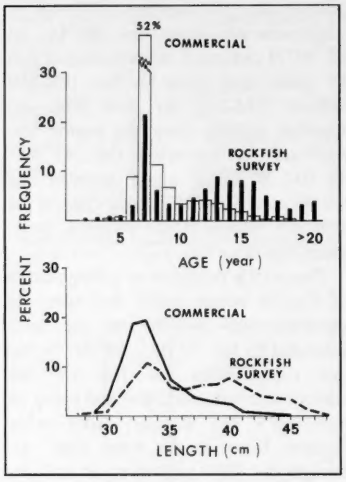

Figure 7.—Top: Age composition of Pacific ocean perch sampled at the dock (open bars), and sampled during the rockfish survey (dark bars), in 1977 in the INPFC Columbia area. Bottom: Length frequency distribution of Pacific ocean perch sampled at the dock (solid line), and sampled during the survey (broken line), for same.

samples were taken. Figures 8 through 11 show the length frequency composition by depth interval in the Eureka, Columbia, and Vancouver areas. The modes in length frequency composition reflect the modal distribution in age composition in most strata where age samples were taken.

In the Eureka area (lat. 40°26′-42°59′N) there was a conspicuous absence of larger, presumably older fish at all depths. The mode at 33 cm in 100-149 fathoms (183-272 m) indicated the presence of the 1970 year class. Within the Columbia area the 1970 year class was dominant from 100 to 250 fathoms (183-457 m) between lat. 43°00′ and 44°59′N and from 50 to 199 fathoms (91-364 m) between lat. 45°00′ and 46°43′N. Further north in the Columbia area (lat. 46°44′-47°29′N), the length frequencies shifted to larger fish.

Size composition data from samples of commercial landings were also available for comparison with the survey data for the INPFC Columbia area (Fig. 7, bottom). The commercial data also showed the dominance of the 1970 year class, but contained a smaller proportion of larger fish than the survey data. Again, this reflects the fishing strategy of the commercial fleet.

The influence of the 1970 year class appears to diminish northerly into the Vancouver area, as greater numbers of large fish appear. One of the Vancouver area samples (lat. 48°01′N, 140 fathoms) appeared to influence the length frequency distribution substantially due to a very large catch (3,020 kg) with a modal length of 46 cm.[1] A geographic shift in length can be clearly seen in the composite Figure 12, where all depth intervals were combined for each area.

[1]Unfortunately, no otolith sample was collected for this tow.

The appearance of larger fish with increasing latitude may be an indication of a pattern of recruitment from south to north. Evaluation of this hypothesis, however, is confounded by the fact that closures to foreign fishing exist from lat. 46°00′ to 47°00′ N and from 47°30′ to 48°30′ N which may have allowed the build-up (and conservation) of older, larger perch. In addition, there were 60 percent females in the Vancouver area as opposed to 49 percent in the Columbia area, a situation which would account for some of the differences in size composition. Also, the inherent patchiness and variability of rockfish size and abundance between samples make it difficult to generalize about length frequency distributions for Pacific ocean perch from one geographic area to the next.

Growth

The growth of Pacific ocean perch sampled in depths of 100-149 fathoms (183-272 m) was compared with their growth in 150-199 fathoms (274-364 m) for lat. 45°00′-46°43′N (Columbia area) and lat. 47°50′-48°30′N (Vancouver area). No significant differences ($P \geq 0.05$) were detected between L_∞, k, and t_0 parameters of males and females between depth intervals in the Columbia area (Table 3). Highly significant differences occurred between depth intervals for estimates of k for male perch in the Vancouver area ($Z = 2.61$, $P \geq 0.01$), together with significant differences between estimates of t_0 ($Z = 1.97$, $P \geq 0.05$). There were no significant differences in L_∞ between the two depth strata. Males sampled in 100-149 fathoms had higher values for k and t_0 ($k = 0.170$ and $t_0 = -1.64$) compared with those in 150-199 fathoms ($k = 0.080$ and $t_0 = -8.65$). No significant differences were found between depth strata for estimates of L_∞, k, and t_0 for female Pacific ocean perch in the Vancouver area.

Male Pacific ocean perch sampled from 100 to 149 fathoms (183-272 m) in the Columbia area had a significantly higher estimate for L_∞ ($L_\infty = 47.0$ cm) compared with the Vancouver area

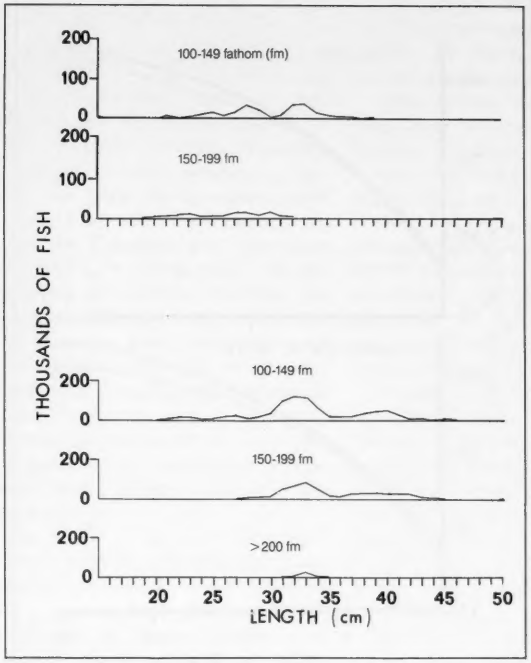

Figure 8.—Length frequency distribution of Pacific ocean perch sampled during the 1977 rockfish survey for INPFC Eureka area (lat. 40°26′-42°59′N) (top) and the southern portion of the INPFC Columbia area (lat. 43°00′-44°59′N) (bottom). Samples were expanded to the total population.

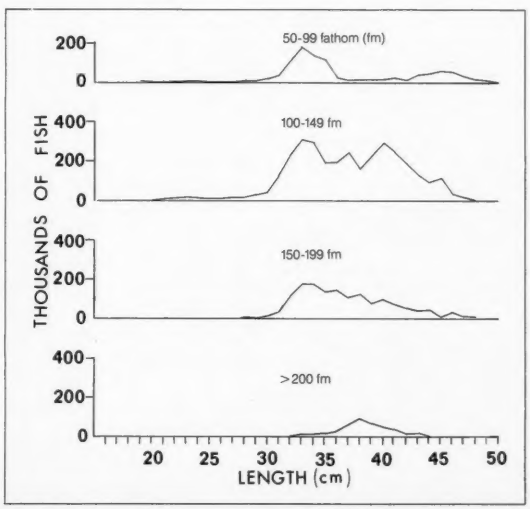

Figure 9.—Length frequency distribution of Pacific ocean perch sampled during the 1977 rockfish survey for the middle portion of the INPFC Columbia area (lat. 45°00′-46°43′N), expanded to the total population.

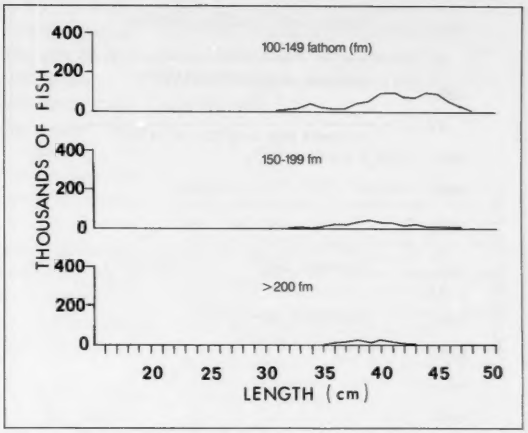

Figure 10.—Length frequency distribution of *S. alutus* sampled during the 1977 rockfish survey for the northernmost portion of the INPFC Columbia area (lat. 46°44′-47°29′N), expanded to the total population.

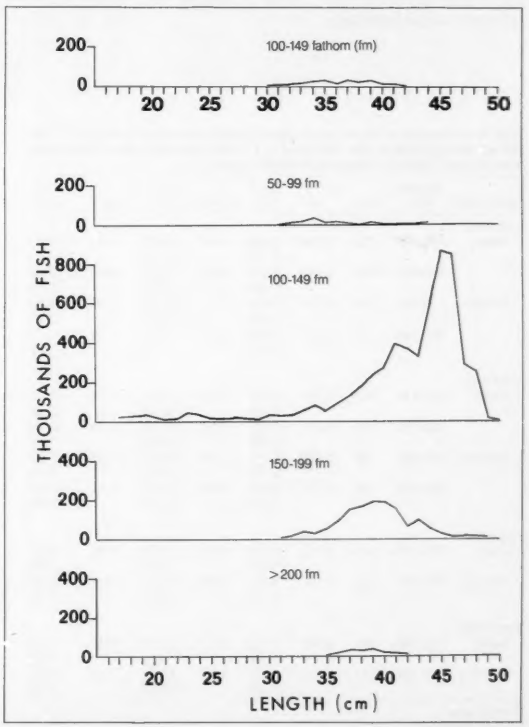

Figure 11.—Length frequency distribution of Pacific ocean perch sampled during the 1977 rockfish survey for the INPFC Vancouver area (lat. 47°30′-47°50′N, top; lat. 47°51′-48°30′N, bottom), expanded to the total population.

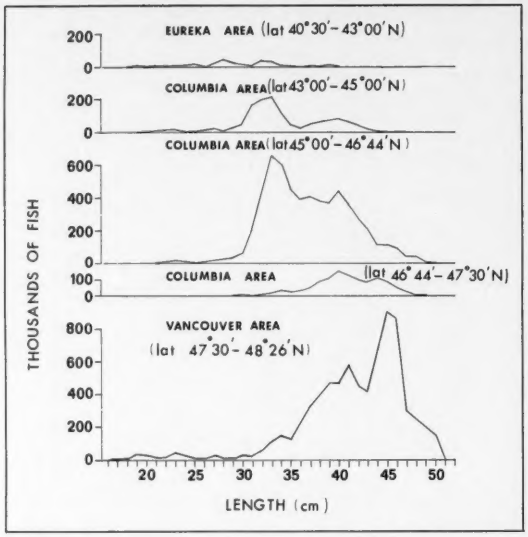

Figure 12.—Size composition of Pacific ocean perch (sexes and depth intervals combined) caught by INPFC area during the 1977 synoptic rockfish survey.

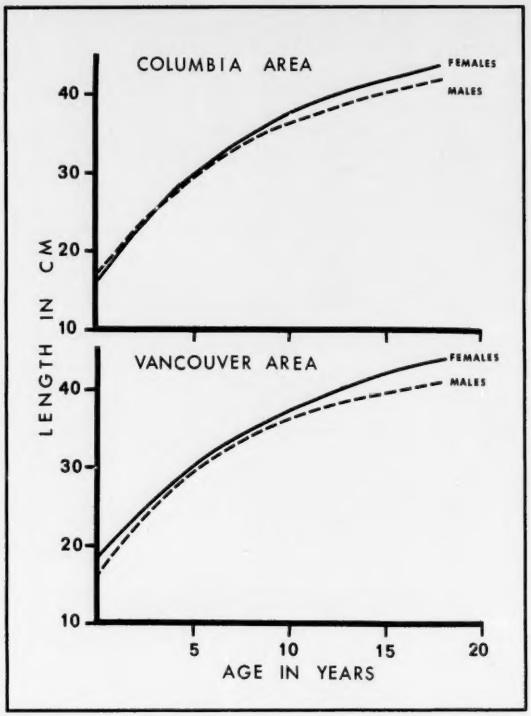

Figure 13.—Growth-in-length curves fitted by von Bertalanffy equation for Pacific ocean perch from INPFC Columbia and Vancouver areas (100-199 fathoms).

Table 3.—Estimates of Pacific ocean perch growth parameters at depths of 100-149 fathoms compared with estimates at 150-199 fathoms in two international North Pacific Fisheries Commission (INPFC) areas.

INPFC area	Depth (fm)	n[1]	k[2]	L.L.[3] U.L.	L_∞ (cm)[4]	L.L.[3] U.L.	t_0[5]	L.L.[3] U.L.
Columbia								
Males	100-149	433	0.099	0.062	47.00	43.28	−4.86	−7.57
				0.137		50.72		−2.15
	150-199	[6]184	0.125	0.057	43.92	39.88	−4.09	−8.02
				0.193		47.96		−0.16
Females	100-149	474	0.105	0.074	49.10	46.00	−3.82	−5.83
				0.137		52.20		−1.82
	150-199	74	0.071	0.000	53.01	38.74	−6.92	−14.74
				0.142		67.26		0.90
Vancouver								
Males	100-149	304	0.170	0.130	42.30	41.17	−1.64	−3.25
				0.210		43.43		−0.02
	150-199	[7]176	0.080	0.026	46.17	40.00	−8.65	−15.42
				0.134		52.34		−1.87
Females	100-149	128	0.096	0.049	51.30	45.60	−4.05	−7.32
				0.142		57.00		−0.79
	150-199	[7]64	0.110	−0.011	45.07	37.67	−5.76	−15.76
				0.230		52.47		4.25
Columbia								
Males	100-199	621	0.110	0.079	45.74	43.28	−4.36	−6.41
				0.141		48.20		−2.31
Females	100-199	548	0.100	0.071	49.53	46.44	−4.24	−6.20
				0.128		52.62		−2.28
Vancouver								
Males	100-199	481	0.134	0.102	43.14	41.73	−3.57	−5.48
				0.166		44.55		−1.67
Females	100-199	191	0.097	0.046	49.39	43.98	−4.67	−8.52
				0.148		54.80		−0.82

[1]Sample size.
[2]Growth coefficient.
[3]95 percent confidence interval, L.L. = lower limit, U.L. = upper limit.
[4]Asymptotic length.
[5]Hypothetical length (cm) at age 0.
[6]Pacific ocean perch ages from 6 to 16 years.
[7]Pacific ocean perch ages from 7 to 18 years.

males from the same depth ($L_\infty = 42.3$ cm, $Z = 2.37$, $P \geq 0.02$). For the same comparison, estimates of k were significantly lower for Columbia area males ($k = 0.099$) compared with those in the Vancouver area ($k = 0.170$, $Z = 2.52$, $P \geq 0.02$). Significant differences occurred between t_0 estimates for male Pacific ocean perch sampled from 100 to 149 fathoms between the Columbia and Vancouver areas with $t_0 = -4.86$ and -1.64, respectively ($Z = 2.00$, $P \geq 0.05$). No significant differences for estimates of L_∞, k, and t_0 were detected between males sampled from 150-199 fathoms between the Columbia and Vancouver areas. There were also no significant differences for estimates of L_∞, k, and t_0 between females sampled in the Columbia and Vancouver areas in either depth interval.

The width of the 95 percent confidence intervals indicated that more variation was associated with estimates of L_∞, k, and t_0 for Pacific ocean perch sampled in the deeper interval when compared with those sampled from 100 to 149 fathoms. This may be due to the smaller sample sizes in deeper water as well as the effects of changes in age composition between depth strata.

After pooling the data from each depth interval (even though some differences occurred for estimates of k and t_0 for Vancouver males between depth strata), no significant differences in the L_∞, k, or t_0 values were present between Pacific ocean perch from the INPFC Columbia and Vancouver areas ($P \geq 0.05$). Age-length relationships predicted by the von Bertalanffy parameters from the pooled samples are shown in Figure 13.

Growth parameters estimated from the 1977 rockfish data for the INPFC Vancouver area are similar to those reported by Gunderson (1977) for Pacific ocean perch sampled in 1972. Males from the Vancouver area in that study had L_∞, k, or t_0 values of 43.15 cm, 0.1320, and -2.1186 years, respectively, with a standard error of the estimate equal to 0.68. Females had values of 48.47 cm, 0.0908, -3.5041 years, respectively, with a standard error of the estimate equal to 0.45. All of these values fell within the 95 percent confidence interval of the 1977 rockfish survey estimates for the Vancouver area.

Literature Cited

Gunderson, D. R. 1977. Population biology of Pacific ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte Sound region, and their response to fishing. Fish. Bull., U.S. 75:369-403.

———, and T. M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish.Rev. 42(3-4):2-16.

———, S. J. Westrheim, R. L. Demory, and M. E. Fraidenburg. 1977. The status of Pacific ocean perch (*Sebastes alutus*) stocks off British Columbia, Washington, and Oregon in 1974. Environ. Can., Fish. Mar. Serv., Tech Rep. 690, 63 p.

Tomlinson, P. K., and N. J. Abramson. 1961. Fitting a von Bertalanffy growth curve by least squares. Calif. Dep. Fish Game, Fish Bull. 116, 69 p.

Westrheim, S. J. 1973. Age determination and growth of Pacific ocean perch (*Sebastes alutus*) in the northeast Pacific Ocean. J. Fish. Res. Board Can. 30:235-247.

———, D. R. Gunderson, and J. M. Meehan. 1972. On the status of Pacific ocean perch (*Sebastes alutus*) stocks off British Columbia, Washington, and Oregon in 1970. Fish. Res. Board Can., Tech. Rep. 326, 48 p.

Size Composition, Age Composition, and Growth of Chilipepper, *Sebastes goodei*, and Bocaccio, *S. paucispinis*, From the 1977 Rockfish Survey

MARK E. WILKINS

Introduction

Rockfish of the genus *Sebastes* are a significant component of commercial and sport fisheries off the U.S. Pacific coast. Landings of rockfish have heretofore been reported only by two categories, "*Sebastes alutus*" and "other rockfish" (Gunderson[1]). Consequently, the management of rockfish resources, including over 60 species, has been based on these two taxonomic groupings.

The differences in growth rate, age and size at maturity, and maximum size among the species included in the "other rockfish" category are substantial (Phillips, 1964; Chen, 1971; Westrheim and Harling, 1975), indicating that responsible management of these species demands their separation into more homogeneous groupings on the basis of population biology characteristics. One of the main objectives of the 1977 rockfish survey was to gather such information on the major species included in the "other rockfish" category. Presented here are the results of an investigation of growth, size composition, and age composition of two species important in commercial and sport fisheries off California: Chilipepper, *S. goodei*, and bocaccio, *S. paucispinis*.

Materials and Methods

During the 1977 rockfish survey, the following length frequency and age-length data were collected from demersal trawl samples of chilipepper and bocaccio between lat. 34°09′ and 46°16′N and within the bottom depth interval of 50-200 fathoms (91-366 m):

	Otoliths collected			Length frequency observations		
	No. of hauls	Sex		No. of hauls	Sex	
Species		M	F		M	F
S. goodei	24	958	1,194	56	2,273	3,105
S. paucispinis	6	199	187	34	726	635

All lengths were measured as fork length to the nearest centimeter. Otoliths (sagittae) were collected for age determination, having been determined by Six and Horton (1977) to be the best aging structure for *Sebastes*. Random samples were taken for length frequency and otolith collections from hauls with relatively large catches of the target species. Otoliths from each haul were stored separately by sex-centimeter groups in vials with 50 percent ethanol solution. The otoliths were later read by the fish aging unit of the Northwest and Alaska Fisheries Center, National Marine Fisheries Service (NMFS), Seattle, Wash.

Since the main spawning seasons of these two species occur between mid-November and mid-March (Phillips, 1964), the specimens measured during the midsummer 1977 rockfish survey had presumably attained half of their annual growth. Consequently, one-half year was added to the age of all fish aged in this study. This enabled me to compare these data with those of Phillips (1964), who used the technique of back-calculation to derive his age-length relationships. When ages are referred to in the text, however, they will be rounded down (i.e., age 5.5 fish will be referred to as age 5).

Age-length keys were compiled by species and sex in each of the latitude-depth areas where data were collected, as well as for various combinations of these areas. Mean lengths at age, derived from these age-length keys, were used to estimate parameters of the von Bertalanffy growth model:

$$l_t = L_\infty (1 - e^{-k(t-t_0)})$$

where l_t = length at age t,
L_∞ = asymptotic length for the species,
k = growth completion rate, and
t_0 = theoretical age at zero length.

[1]Gunderson, D. R. 1976. Proceedings of the first rockfish survey workshop. Unpubl. manuscr., 17 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

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ABSTRACT—Size and age compositions were compiled from length measurements and otolith samples of chilipepper, Sebastes goodei, *and bocaccio,* S. paucispinis, *from trawl catches off California (lat. 34°09′-40°16′N) during the 1977 rockfish survey. Within each species, similar growth patterns were observed throughout this range. Von Bertalanffy growth parameter estimates, in general, were similar to published values. For both species, females grew faster than males after the mean length at maturity had been reached. Size composition and age composition plots indicated offshore movements of older fish of both species, chilipepper beginning to move into the 100-199 fathom (183-364 m) depth zone rather abruptly between ages 4 and 5, and bocaccio beginning to move out more gradually between ages 3 and 7. Mean size for both sexes of both species increased with latitude. With all areas, depths, and sexes combined, age-class strength of chilipepper was notably weak at age 3 and greatest at age 5, and bocaccio age-class strength was greatest at age 4.*

The method of Fabens (1965) was used for these estimates.

Length frequency observations, weighted by catch per unit effort (numbers/kilometer) and expanded to the total estimated population size, were plotted for various combinations of latitude-depth areas. Final groupings of latitude-depth areas were made by considering characteristics of growth curves and size composition for each of the areas. Data from areas showing similar characteristics were grouped, as were data from areas with few observations. Age compositions for the final geographic groupings were estimated by applying the appropriate size composition data to the final age-length keys.

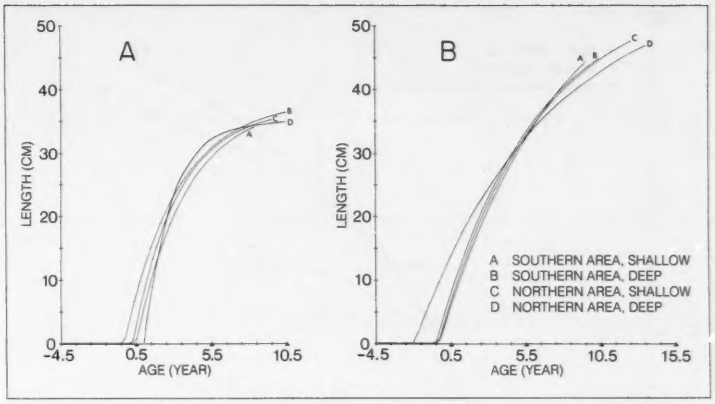

Figure 1.—Von Bertalanffy growth curves for chilipepper males (A) and females (B) from the four latitude-depth strata. Latitude divisions are 34°09′-37°07′N (southern) and 37°07′-40°16′N (northern), and depth zones are 50-99 fathoms (91-181 m) and 100-199 fathoms (182-364 m).

Results

Growth

Within sexes, growth curves and mean lengths at age were similar among all latitude-depth groupings of chilipepper (Fig. 1), although males and females showed quite different growth patterns. Growth curves and mean lengths at age were less uniform for the various groupings of bocaccio but only a relatively small number of observations was available from any of the individual latitude-depth areas. As with chilipepper, male and female bocaccio exhibited different growth patterns.

On the basis of the above considerations, all age-length data were pooled for each sex of each species and growth parameters were estimated by fitting the mean length at age data to the von Bertalanffy equation. Best fits for both species usually resulted from using mean lengths at age derived from more than five observations and omission of the youngest age class present (where the mean length at age is biased due to incomplete recruitment). Mean length at age (Tables 1 and 2), growth parameters (Table 3), and growth curve plots (Fig. 2, 3) are presented for both species.

Table 1.—Number of readable otoliths examined, mean length at age, and standard deviation for chilipepper.

Males				Females			
Age	N	$\bar{L}$	s	Age	N	$\bar{L}$	s
1.5	22	16.9	0.8	1.5	20	17.0	0.6
2.5	135	21.4	1.7	2.5	166	21.8	1.7
3.5	50	24.8	2.2	3.5	89	25.2	2.5
4.5	166	30.3	1.8	4.5	144	31.8	3.2
5.5	173	31.5	1.6	5.5	178	34.6	2.7
6.5	114	33.1	1.8	6.5	112	37.5	2.9
7.5	109	34.6	1.8	7.5	137	40.9	2.6
8.5	113	35.4	1.7	8.5	121	42.9	2.2
9.5	42	36.7	3.6	9.5	82	44.9	2.6
10.5	21	36.3	1.1	10.5	58	46.7	2.6
11.5	9	37.9	0.8	11.5	38	48.3	2.6
12.5	4	36.5	2.6	12.5	29	48.2	1.7
—	—	—	—	13.5	13	48.3	2.1
—	—	—	—	14.5	6	49.2	1.7
—	—	—	—	15.5	1	50.0	—

Table 2.—Number of readable otoliths examined, mean length at age, and standard deviation for bocaccio.

Males				Females			
Age	N	$\bar{L}$	s	Age	N	$\bar{L}$	s
2.5	2	34.5	2.1	2.5	5	33.4	1.7
3.5	23	38.2	3.8	3.5	18	39.1	4.1
4.5	41	42.0	3.0	4.5	37	43.1	2.8
5.5	45	44.2	3.6	5.5	30	45.5	3.8
6.5	22	47.8	4.7	6.5	31	51.4	5.4
7.5	22	56.3	3.5	7.5	26	57.9	4.5
8.5	18	58.1	3.6	8.5	19	63.4	3.3
9.5	20	58.9	2.9	9.5	10	66.4	3.6
10.5	5	63.2	3.5	10.5	6	65.5	3.7
11.5	1	58.0	—	11.5	2	66.5	2.1
—	—	—	—	12.5	1	68.0	—
—	—	—	—	13.5	2	73.0	1.4

Table 3.—Von Bertalanffy growth model parameter estimates for chilipepper and bocaccio as derived from selected mean length at age data collected during the 1977 rockfish survey.

Species	Range in age and length (of selected data) Age (yr)	Length (cm)	L_∞	k	t_0	SD
S. goodei						
Males	2.5-11.5	18-48	38.66	0.30	−0.15	0.71
Females	2.5-14.5	17-53	53.19	0.18	−0.43	0.88
S. paucispinis						
Males	3.5-9.5	32-64	76.58	0.13	−1.81	2.47
Females	2.5-10.5	31-71	87.76	0.11	−1.73	2.60

Size and Age Composition

The size composition for both species differed considerably above and below 100 fathoms with the smaller size classes attaining their highest relative abundance inside 100 fathoms (183 m). Latitudinal differences, although somewhat less distinct than depth differences, generally took the form of larger fish in more northern waters. Final groupings separated size composition data latitudinally at lat. 37°07′N and bathymetrically at 100 fathoms (183 m) for both species, forming four final latitude-depth areas. Plots of length frequency data for these final

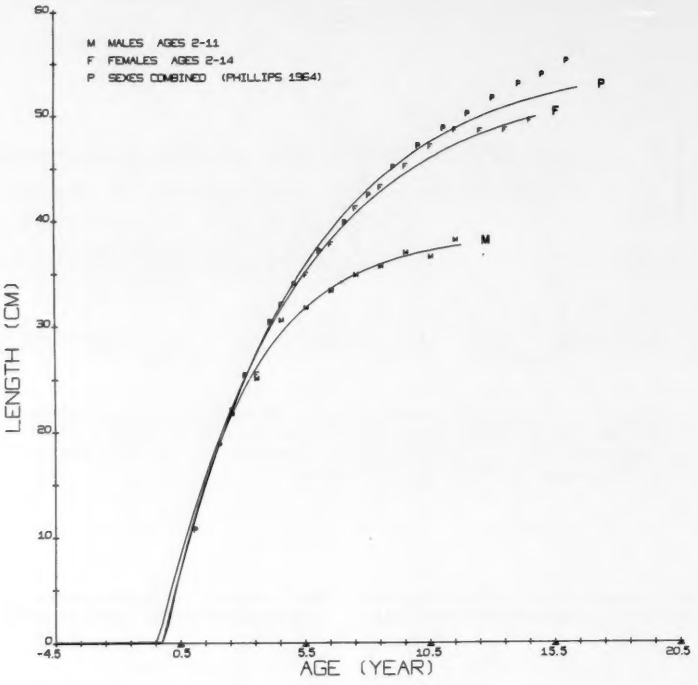

Figure 2.—Von Bertalanffy growth curves for chilipepper and mean lengths at age used to fit the curves (small symbols). (M) males from entire 1977 survey area (fork length), (F) females from entire 1977 survey area (fork length), and (P) sexes combined from Phillips (1964) (total length).

areas are presented for chilipepper (Fig. 4) and bocaccio (Fig. 5) by sex and with sexes combined. Age composition data for these same areas are presented in Figures 6-8 (chilipepper) and Figures 9-11 (bocaccio).

Discussion

Age-length keys compiled for male and female chilipepper (Table 1) showed similar mean lengths at age for both sexes through age 3. Females exhibited much faster growth from age 4 onward. The size at which the growth patterns diverge is about 30 cm. This divergence occurs near the onset of maturation for males, since Gunderson et al. (1980) found mean size at maturity to be 26.1 cm for males and 37.0 cm for females.

Some adjustments in the growth curves were needed to facilitate comparison with results from Phillips (1964). The half-year increments added to the ages of chilipepper from the 1977 survey were effectively removed by calculating mean lengths at last birthday via the von Bertalanffy equation. This was done for each sex and averaged to provide estimated mean lengths at last birthday for a mixed-sex sample. Mean total lengths at age from Phillips were converted to fork length by the following relationship provided by W. H. Lenarz (pers. commun.): FL(mm) = −3.139944 + 0.949641 TL(mm). The resultant mean lengths at age from Phillips could then be compared with

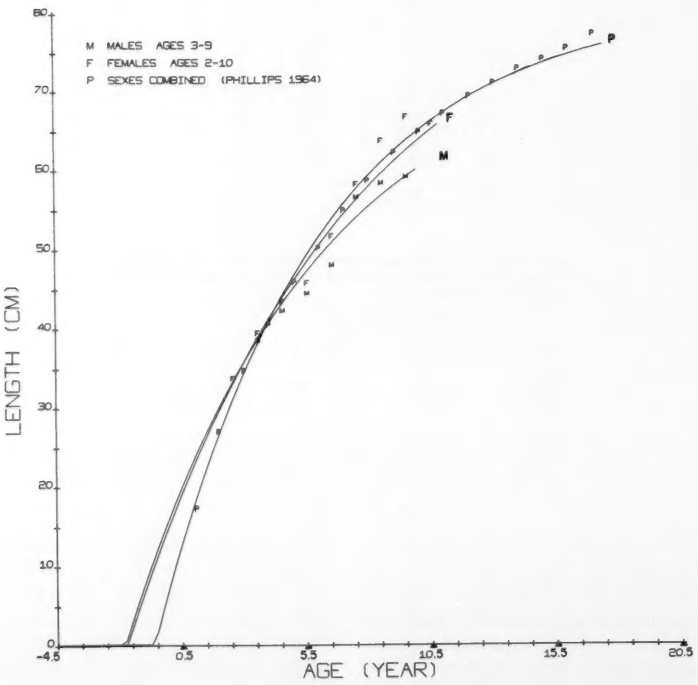

Figure 3.—Von Bertalanffy growth curves for bocaccio and mean lengths at age used to fit the curves (small symbols). (M) males from entire 1977 survey area (fork length), (F) females from entire 1977 survey area (fork length), and (P) sexes combined from Phillips (1964) (total length).

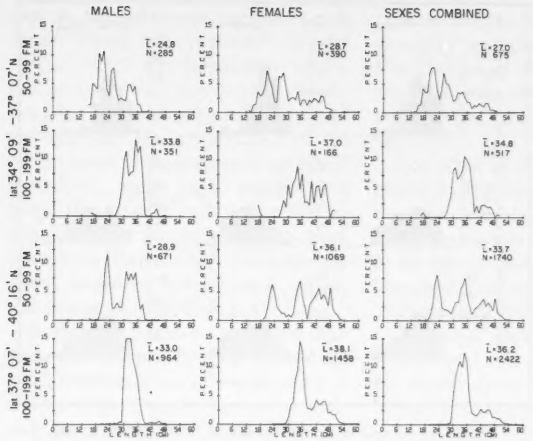

Figure 4.—Expanded size composition of chilipepper for the four final latitude-depth areas including mean length ($\bar{L}$) and number of length frequency observations upon which the estimates are based (N).

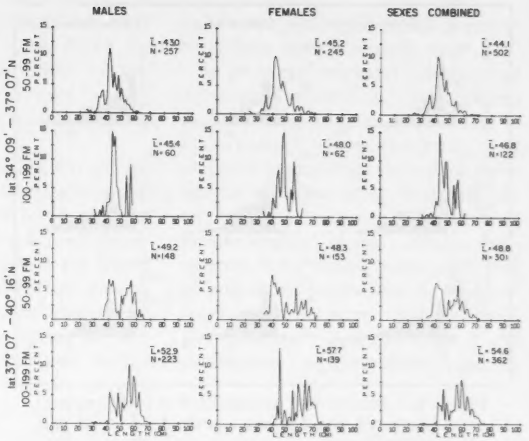

Figure 5.—Expanded size composition of bocaccio for the four final latitude-depth areas including mean lengths ($\bar{L}$) and number of length frequency observations upon which the estimates are based (N).

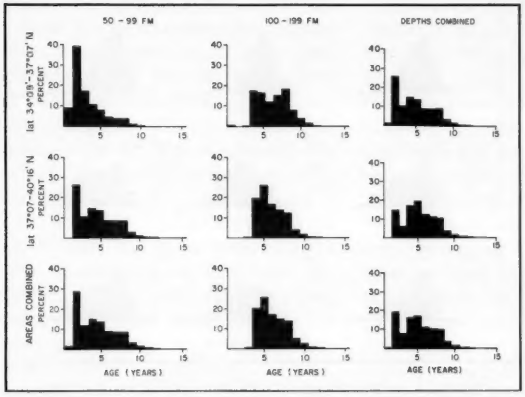

Figure 6.—Percent age composition for chilipepper males for the four latitude-depth strata and combinations thereof.

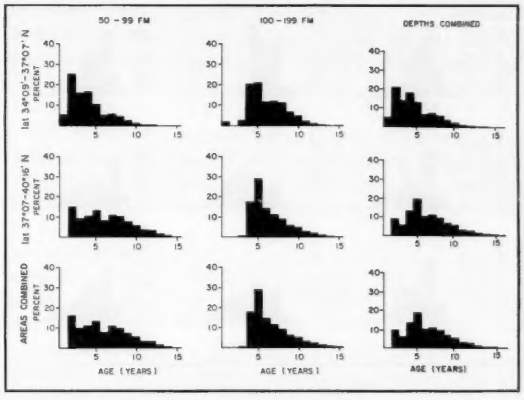

Figure 7.—Percent age composition for chilipepper females for the four latitude-depth strata and combinations thereof.

mean lengths at last birthday from the simulated mixed-sex sample of 1977 chilipepper.

For chilipepper aged 1 and 2 years, mean lengths at age from Phillips' data were 1.9 and 1.2 cm less, respectively, than those from the 1977 survey. Agreement was close (within 0.6 cm) for ages 3-7. For fish aged 9-15, Phillips' mean lengths were greater than those from this survey by an increasing margin of 2.4 to 6.6 cm. The discrepancy at ages 1 and 2 is likely due to Phillips' use of back-calculation (and the associated bias caused by Lee's phenomenon) for nearly all observations in these age classes. The difference in sizes at older ages may be due to Phillips' use of scales, although he did not feel he had missed any outer rings. The similarity between the growth curves of Phillips (sexes combined) and that of female chilipepper from this survey (Fig. 2) suggests another reason. If Phillips used a sampling scheme of length-stratified sampling without regard to sex, the larger size classes would have been composed of an increasing proportion of females, producing an upward bias in the right-hand side of his curve.

The growth curves for male and female chilipepper (Fig. 2) show a distinct difference in growth patterns. Females reach a much greater maximum length (L_∞) but the rate at

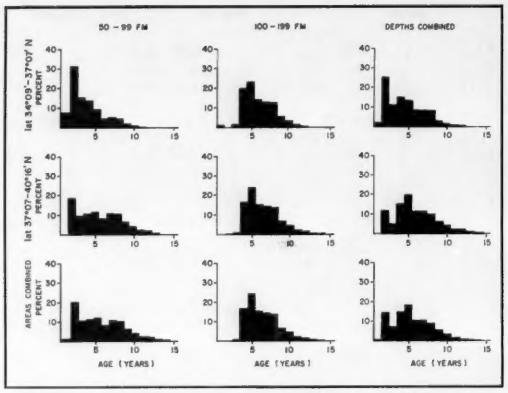

Figure 8.—Percent age composition for chilipepper, sexes combined, for the four latitude-depth strata and combinations thereof.

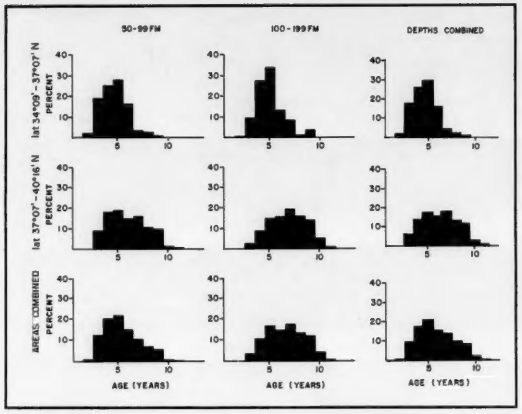

Figure 9.—Percent age composition for bocaccio males for the four latitude-depth strata and combinations thereof.

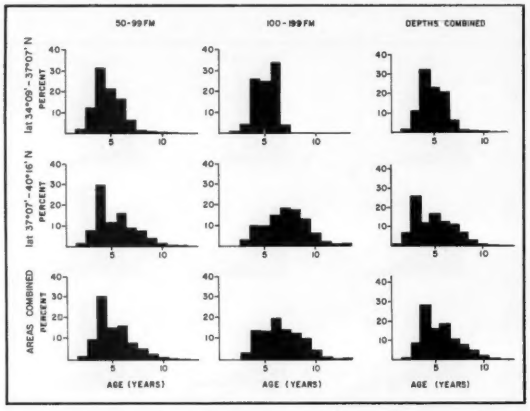

Figure 10.—Percent age composition for bocaccio females for the four latitude-depth strata and combinations thereof.

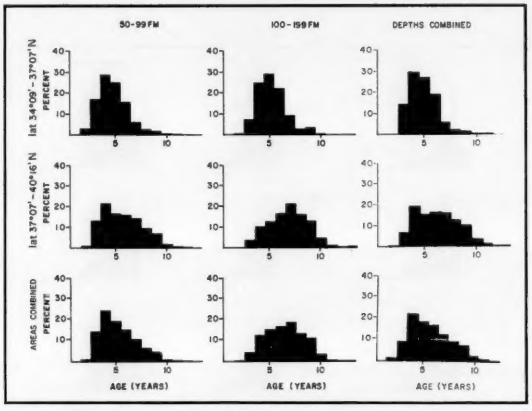

Figure 11.—Percent age composition for bocaccio, sexes combined, for the four latitude-depth strata and combinations thereof.

which that length is approached (k) is much less than for males. Parameter estimates for the von Bertalanffy growth model (Table 3) cannot be compared directly with Phillips' results because sexes were not separated in that work, and Phillips' parameters refer to fish measured in terms of total length. However, the growth completion rate constant (k) and maximum length (L_∞) found by Phillips for sexes combined were 0.18 and 55.3 cm, respectively, which are similar to those found for females in this investigation.

Size composition plots (Fig. 4) for chilipepper showed that smaller fish (<25 cm) were found almost exclusively inside 100 fathoms (183 m). Upper ranges of length appeared similar for each sex, regardless of depth or latitudinal groupings. Mean lengths generally increased with latitude.

Age composition plots (Fig. 6-8) again show the trend of younger chilipepper inside 100 fathoms (183 m) beginning to appear in significant quantities in deeper water as 4 and 5 year olds. The time of movement into deeper water corresponds closely with ages extrapolated from mean size at maturity (Gunderson et al., 1980). The proportion of older fish is greater in deeper waters but the range of ages is usually similar, regardless of depth. The differences in age composition between northern and southern areas are not as

clear as the differences between depth zones. Young fish constitute a greater proportion of the population in the southern area than they do in the northern area, while the opposite is true of the older age-classes. Because of the dissimilarities between depth zones and latitudinal areas, age composition (population size at each age) was estimated by sex for each latitude-depth stratum and then combined to obtain the age composition data for areas, sexes, and depths combined (Fig. 8).

Notable features of the total age composition for chilipepper include the weak representation of 3-year-old fish and the high relative abundance of 4- and 5-year-old fish in all areas. A further characteristic of these estimates is that abundance tends to taper off systematically between ages 7 and 14.

Mean lengths at age for male and female bocaccio were found to be very similar through age 5 (Table 2). Females began to noticeably outgrow males around age 6 (Fig. 3). As with chilipepper, the size at the point at which the growth curves of male and female bocaccio diverge corresponds closely with the size at maturity for males (44.8 cm) reported by Gunderson et al. (1980).

For comparison with data from Phillips (1964), bocaccio mean lengths were standardized as they were for chilipepper. The total length to fork length conversion used for bocaccio (Lenarz, pers. commun.) was: FL(mm) = 2.016508 + 0.956098 TL(mm). Mean lengths for the first three observed age classes in the 1977 survey (ages 2, 3, and 4) were 4.0, 2.6, and 1.9 cm longer, respectively, than those from Phillips' study. Fish aged 5 and 6 years agreed more closely with Phillips' data, exceeding his mean lengths at these ages by 1.5 and 1.4 cm, respectively. Agreement was very close (within 0.6 cm) for ages 7 through 13. The discrepancy at ages 2-4 is again likely due to Phillips' use of back-calculation and the associated Lee's phenomenon bias. This might also be the cause of the smaller differences seen at ages 5 and 6.

Mean lengths at age from this study generally exceeded those found by Westrheim and Harling (1975) by considerable margins. However, survey areas of the two studies were widely separated.

The range of lengths at each age appeared to be much broader for bocaccio than for chilipepper. When examining this phenomenon, there did not appear to be any distinct modes in the length distributions of most of the age classes. This appeared to be indirect evidence of a protracted spawning period for this species and was substantiated further by observations of maturity stages. Maturity observations made in July and early August showed about half of bocaccio females to be sexually inactive, but quite a significant proportion (24 percent) were either approaching spawning (visible embryos) or recently spent. Another 24 percent were either maturing or recently fertilized (Gunderson et al., 1980). These results are somewhat contradictory to the bimodal spawning pattern, with modes in November and March, found by Moser (1967) for bocaccio off southern California and seem to indicate that the spawning period is more protracted than previously suggested.

Size composition data for bocaccio (Fig. 5) indicate that the smallest size classes have their highest relative abundance inside 100 fathoms (183 m). Upper size ranges did not vary by depth, but larger fish were found in the northern area than in the southern area. Mean lengths increased with depth and with latitude.

Age composition plots for bocaccio (Fig. 9-11) further indicate that smaller, younger fish attain their highest relative abundance in shallow waters. Age distributions for the shallower areas are noticeably skewed toward the younger ages, while those for the deeper waters appear more normal. This indicates that there is a distinct tendency for fish to move to deeper water as they become older. The left side of the plots for 100-199 fathoms (183-364 m) depths show a more gradual increase for bocaccio than for chilipepper, indicating a more prolonged period of movement from shallow to deep water.

In all areas, bocaccio younger than age 3 were rare, and age 3 fish appeared to be incompletely recruited. Age 5 males and age 4 females were the most abundant year classes in shallow water in both latitudinal areas. In deeper water, age 5 males and age 6 females were most abundant in the southern area, whereas in the northern area, age 7 fish of both sexes predominated. When all areas and sexes were combined, relative abundance peaked at age 4 and declined very regularly through age 11.

Acknowledgments

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Literature Cited

Chen, L. C. 1971. Systematics, variation, distribution, and biology of rockfishes of the subgenus *Sebastomus* (Pisces, Scorpaenidae, *Sebastes*). Scripps Inst. Oceanogr., Bull. 18, 115 p.

Fabens, A. J. 1965. Properties and fitting of the von Bertalanffy growth curve. Growth 29:265-289.

Gunderson, D. R., P. Callahan, and B. Goiney. 1980. Maturation and fecundity of four species of *Sebastes*. Mar. Fish. Rev. 42(3-4):74-79.

Moser, H. G. 1967. Reproduction and development of *Sebastodes paucispinis* and comparison with other rockfishes off southern California. Copeia 1967:773-797.

Phillips, J. B. 1964. Life history studies on ten species of rockfish (genus Sebastodes). Calif. Dep. Fish Game, Fish Bull. 126, 158 p.

Six, L. D., and H. F. Horton. 1977. Analysis of age determination methods for yellowtail rockfish, canary rockfish, and black rockfish off Oregon. Fish. Bull., U.S. 75:405-414.

Westrheim, S. J., and W. R. Harling. 1975. Age-length relationships for 26 scorpaenids in the northeast Pacific Ocean. Environ. Can., Fish. Mar. Serv., Tech. Rep. 565, 12 p.

Yellowtail Rockfish, *Sebastes flavidus*, Length and Age Composition Off California, Oregon, and Washington in 1977

MICHAEL E. FRAIDENBURG

Introduction

Yellowtail rockfish, *Sebastes flavidus*, is a significant component of the shelf rockfish complex living on the Pacific coast continental shelf. Although living in depths of 0-300 fathoms (0-550 m) (Hart, 1973), this species is most abundant in the 50-100 fathom (91-183 m) depth zone (Alverson et al., 1964; Gunderson and Sample, 1980) where it is associated with canary rockfish, *S. pinniger*, and silvergray rockfish, *S. brevispinis*. The species range extends from San Diego, Calif., to Kodiak Island, Alaska (Hart, 1973), but its center of abundance is from Oregon to British Columbia (Alverson et al., 1964; Westrheim, 1970). Landings in this region by North American trawlers have ranged from approximately 1,600 to 5,000 t annually (Fraidenburg et al., 1977).

In the 1977 survey of rockfishes, yellowtail rockfish were most abundant off northern Oregon and Washington and 97.2 percent of the biomass present was at depths less than 100 fathoms (183 m). Because yellowtail rockfish are an abundant and commercially important species in the rockfish survey area, it was designated as a target species for collection of length and age composition data. To date, the only published data on length or age composition of the stocks or from the fishery in this area are in Alverson et al. (1964).

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Methods

Weighted length compositions were obtained by first calculating the number of fish caught per kilometer by size and sex (C'_{ijkl}):

$$C'_{ijkl} = \frac{s_{ijkl} \cdot C_{ij}}{\sum_{k=1}^{3} \sum_{l=1}^{L} s_{ijkl}} \div km_{ij}$$

where C_{ij} = total number of fish caught, s = number of fish sampled, i = stratum, j = station, k = sex (1 = male, 2 = female, and 3 = unsexed), l = length group, L = number of length groups, and km = kilometers towed.

These C'_{ijkl} values were then summed over all hauls in a stratum and expanded to the total estimated population ($\hat{P}_i$) to obtain the estimated population size for each size and sex group ($\hat{P}_{ikl}$):

$$\hat{P}_{ikl} = \frac{\sum_{j=1}^{J} C'_{ijkl}}{\sum_{j=1}^{J} \sum_{k=1}^{3} \sum_{l=1}^{L} C'_{ijkl}} \cdot \hat{P}_i$$

where J = number of stations for which length frequency data are available.

These length data were then used to examine the need for geographic and bathymetric stratification.

Otoliths were aged by the Washington Department of Fisheries using aging criteria developed by Kimura et al. (1979). Age compositions were calculated in each stratum by decomposing the weighted length frequencies into age compositions utilizing an age-length key developed from the age samples collected during the survey.

Results

A total of 2,288 length measurements and 1,321 usable otolith readings were available from the survey. Length samples were collected from lat. 35°30′ to 48°30′N and age samples from lat. 40°26′ to 40°30′N (Fig. 1).

For each sex, length compositions were examined by a variety of geographic areas and by depth as indicators for data stratification. No substantial differences in length composition were observed by depth, but differences among areas were present. Based on this analysis, all depths were combined, and five separate geographic areas (Fig. 1) were selected as strata (areas) for presenting length and age composition results.

Length compositions (Fig. 2) showed strong modes in all areas. Males showed particularly strong single modes and a cline of generally decreasing mean length and increasing proportion of fish less than 45 cm from north to south. Females had a larger mean size than males in each area and, rather than strong single modes, had many modes over a broader size range. A cline similar to that observed for males was not evident. A cline may

ABSTRACT–Yellowtail rockfish, Sebastes flavidus, *length and age samples from a 1977 survey of rockfishes off California, Oregon, and Washington were analyzed to produce length and age composition data for the area from lat. 35°30′ to 48°30′N. There was evidence of a north to south cline of decreasing size and age. Length composition data showed strong single modes for males and many modes over a broader size range for females. Age composition data showed two prominent modes at 8-10 and 13-14 years old. No major differences in the age-length relationship were noted between areas using data from the survey and data from market samples from Washington's trawl fishery. Data for all areas were pooled to fit a common growth curve for the northern California to Queen Charlotte Sound, British Columbia, region.*

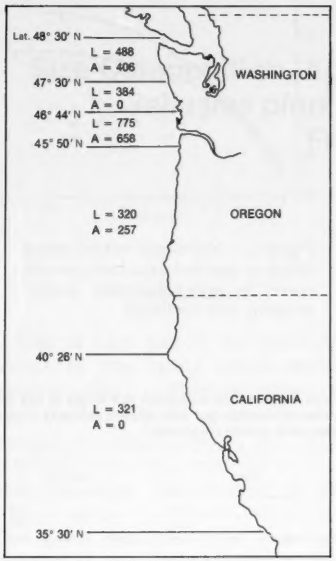

Figure 1.—Areas chosen for analysis of length and age composition of yellowtail rockfish. L = number of length observations in an area and A = number of otolith readings available in an area.

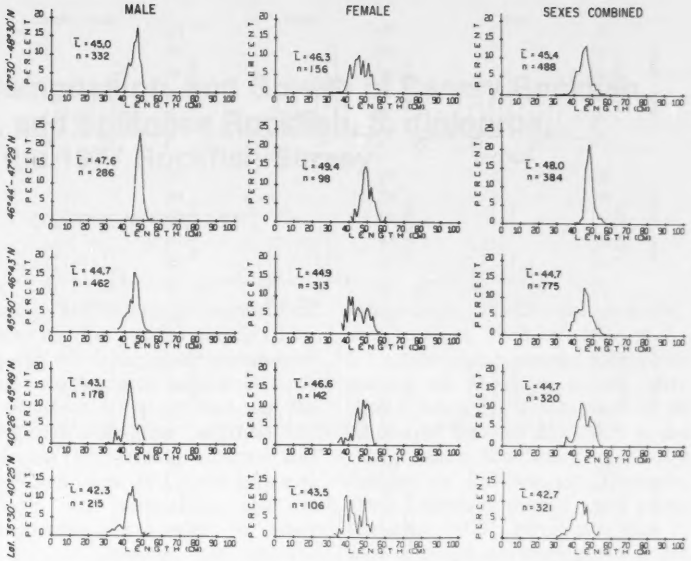

Figure 2.—Size composition of yellowtail rockfish by area and sex.

exist, but low female sample sizes in this study may have obscured such a trend. More data would be desirable for both sexes and future studies of size and age composition should be designed to examine north-south clines in more detail. Sex ratios varied from 74 percent to 56 percent male, with no obvious latitudinal trend (Fig. 2).

The sex ratio data may suggest that a portion of older females were not available to the survey. The lack of exceptionally large fish (Fig. 2) may also suggest this because the record size is reported to be about 66 cm (Hart, 1973).

Prior to construction of the age-length key used for calculating age compositions, mean length at age data from three areas (lat. 40°26′ to 45°49′, 45°50′ to 46°44′, and 47°30′ to 48°30′N) were examined for geographic differences. These data (Fig. 3) did not show any important differences that were consistent among areas, so the data were pooled to produce a single age-length key by sex for decomposing length frequencies into age compositions.

Coastwide age compositions (Fig. 4) show two prominent modes at 8-10 and 13-14 years. For males there is a cline of increasing importance of the 8- to 10-year-old fish from north to south corresponding to the cline observed in length composition data. A demarcation line is evident at lat. 40°50′N where 13- to 14-year-old males were most important to the north and 8- to 9-year-olds most important to the south. For females, a cline or demarcation line is not evident, and excepting the area from lat. 46°44′ to 47°29′N, 8- to 10-year-old fish were most important coastwide.

Growth was estimated by combining rockfish survey data with market sampling data from Washington's trawl fishery for yellowtail rockfish. The details of this analysis are being described by Fraidenburg (in prep.). From this analysis, homogeneous growth was observed in the northern California to Queen Charlotte Sound, British Columbia, region. A total of 4,211 age-length observations were available for

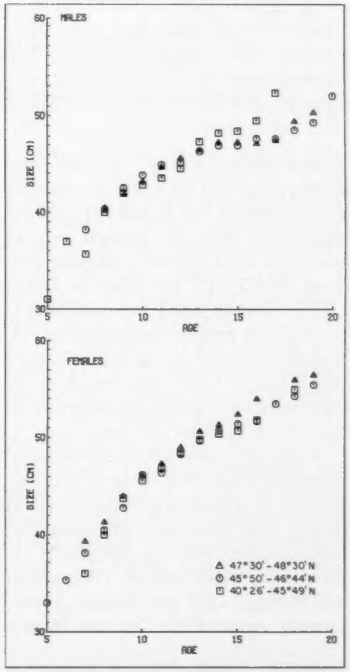

Figure 3.—Mean length at age for yellowtail rockfish by area and sex.

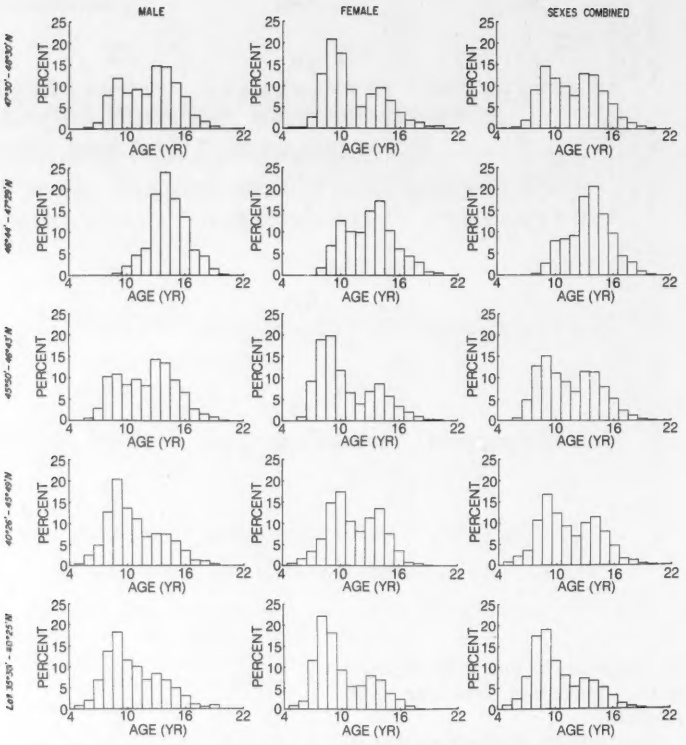

Figure 4.—Age composition of yellowtail rockfish by area and sex.

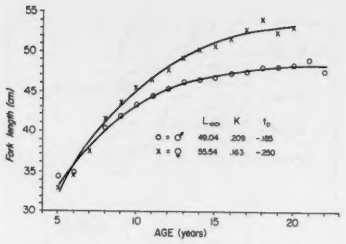

Figure 5.—Yellowtail rockfish mean length at age and calculated growth curves by sex. Survey and market sampling data combined.

Table 1.—Mean and calculated fork length at age for yellowtail rockfish, and least squares estimates of von Bertalanffy growth parameters.

	Male			Female		
Age	Mean	*n*	Calculated	Mean	*n*	Calculated
5	34.38	13	32.45	32.86	22	31.94
6	34.95	19	35.58	34.69	26	35.49
7	37.35	65	38.12	37.34	53	38.50
8	40.26	198	40.18	41.48	128	41.07
9	41.83	193	41.85	43.59	160	43.24
10	43.11	167	43.20	45.37	128	45.09
11	44.43	198	44.31	46.47	117	46.66
12	45.29	278	45.20	47.63	128	48.00
13	46.06	366	45.92	49.31	203	49.13
14	46.43	350	46.51	50.12	230	50.10
15	46.98	278	46.99	50.51	150	50.92
16	47.22	219	47.38	51.76	102	51.61
17	47.59	153	47.69	52.73	44	52.20
18	48.00	114	47.94	54.16	19	52.70
19	48.35	40	48.15	52.20	10	53.13
20	48.42	19	48.32	53.00	5	53.49
21	49.12	8	48.45	50.50	2	—
22	47.67	6	48.57			

	L_∞	k	t_0	L_∞	k	t_0
Est.	49.04	0.209	−0.185	55.54	0.163	−0.250
SD	0.27	0.012	0.386	0.92	0.016	0.549

growth studies. Kimura[1] has described a procedure and provided an example for calculating von Bertalanffy growth parameters using the general purpose nonlinear least squares computer program BMD 07R available in Dixon (1976). This approach was used here to estimate the growth parameters for yellowtail rockfish from the data in Table 1 and Figure 5. Only mean length at age data based on five or more observations were used for these calculations.

A comparison of the results obtained from these data with those of previous workers is presented in Fraidenburg (in prep.). The parameters presented here compared well with von Bertalanffy estimates by other authors (Westrheim and Harling, 1975 and Phillips, 1964). Growth reported by Six and Horton (1977), however, was observed to fit a power function better than a von Bertalanffy and this observation was attributed to a lack of young fish in the samples. It is also possible this could have resulted from low sample size in general and/or a tendency to under-age old fish.

[1]Daniel K. Kimura, Fisheries Biometrician, Washington State Department of Fisheries, M-1 Fisheries Center, University of Washington, Seattle, WA 98195, pers. commun.

Literature Cited

Alverson, D. L., A. T. Pruter, and L. L. Ronholt. 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. H.R. MacMillan Lectures in Fisheries, Inst. Fish., Univ. Brit. Columbia, Vancouver, 190 p.

Dixon, W. J. 1976. *Biomedical computer programs*. Univ. Calif. Press, Los Angeles, 738 p.

Fraidenburg, M., J. E. Smith, W. H. Barss, and T. Jow. 1977. Minimum estimates of the all nation removals, North American trawl species composition and CPUE for "other rockfish" in the northeastern Pacific Ocean. Wash. Dep. Fish., Tech. Rep. 34, 31 p.

Gunderson, D. R., and T. M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev. 42(3-4):2-16.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180, 740 p.

Kimura, D. K., R. R. Mandapat, and S. L. Oxford. 1979. Method, validity, and variability in the age determination of yellowtail rockfish (*Sesbastes flavidus*), using otoliths. J. Fish. Res. Board Can. 36:377-383.

Phillips, J. B. 1964. Life history studies on ten species of rockfish (genus *Sebastodes*). Calif. Dep. Fish Game, Fish Bull. 126, 70 p.

Six, L. D., and H. F. Horton. 1977. Analysis of age determination methods for yellowtail rockfish, canary rockfish, and black rockfish off Oregon. Fish. Bull., U.S. 75:405-414.

Westrheim, S. J. 1970. Survey of rockfishes, especially Pacific ocean perch, in the northeast Pacific Ocean, 1963-66. J. Fish. Res. Board Can. 27:1781-1809.

———, and W. R. Harling. 1975. Age-length relationships for 26 scorpaenids in the northeast Pacific Ocean. Environ. Can., Fish. Mar. Serv., Tech. Rep. 565, 12 p.

Size Composition, Age Composition, and Growth of Canary Rockfish, *Sebastes pinniger*, and Splitnose Rockfish, *S. diploproa*, From the 1977 Rockfish Survey

GEORGE W. BOEHLERT

ABSTRACT–Trawl samples from California to Washington (lat. 34°00'-48°30'N) taken in the 1977 Rockfish Survey were analyzed to provide information on growth, size composition, and age composition of canary rockfish, Sebastes pinniger, *and splitnose rockfish,* S. diploproa. *Canary rockfish were taken predominantly in the Oregon-Washington region at depths of 50-149 fathoms (91-272 m). This species was considered as a single stock; recruitment to the sampling gear and area was complete at ages of approximately 14-15 years and sizes of 51 cm (males) and 55 cm (females). Splitnose rockfish were taken in all areas, at depths of 50-260 fathoms (91-475 m); it was considered in three latitudinal strata (based on differences in growth) and two depth strata (based on differences in length-frequencies). Recruitment to the sampling gear and area was generally complete at ages 14-17 and sizes of 26 cm (males) and 29 cm (females). Fish in the shallow strata were smaller than in the deep strata. In the deep strata there was a general trend of increasing mean size to the north. The size and age compositions in the northern stratum, when compared with historical data, suggest an impact of fishing pressure. It is suggested that the close ecological association of splitnose rockfish with Pacific ocean perch,* S. alutus, *may have resulted in a concomitant decline in stocks due to incidental catches of the former.*

Introduction

Due in large part to the declining stocks of the Pacific ocean perch, *Sebastes alutus*, commercial interest in the "other rockfish" group has increased. A major goal of the 1977 Rockfish Survey was to provide biological population characteristics of the various species of *Sebastes* composing the "other rockfish" group as a data base for management decisions on regulation of the fishery. Very little information is available on the species of the "other rockfish" group. Reports dealing with this fishery at the species level have been few; most notable are those of Alverson et al. (1964) for the Oregon-Washington region and Heimann (1963) for the Monterey Bay (California) area. This report deals with growth, size composition, and age composition within stocks of canary rockfish, *S. pinniger*, and splitnose rockfish, *S. diploproa*.

The canary rockfish is an important component of the sport and commercial fisheries. This species reaches a maximum size of 76 cm; it inhabits a depth range from the surface (juveniles) to 150 fathoms (274 m), and a latitudinal range from Baja California to Alaska (Miller and Lea, 1972), although commercial quantities are present only from central California waters to Dixon Entrance, Alaska. Off California, the principal catch of this species is in the sport and commercial longline catch; it is of minor importance in the trawl fishery (Miller and Gotshall, 1965; Heimann, 1963). Off Oregon, however, it is a dominant species in the trawl catch of the "other rockfish" group in depths less than about 120 fathoms (219 m) (Fraidenburg et al., 1977).

The splitnose rockfish is a smaller species, reaching a maximum size of 46 cm and inhabiting a range from Baja California to Alaska at depths of 100-260 fathoms (183-475 m) (Miller and Lea, 1972). This species enters the fishery largely as incidental catch (Nitsos and Reed, 1965; Alverson et al., 1964), although a directed fishery was present off Monterey in the early 1960's, when this species made up 44 percent of the total fish catch in the "deep water sub-fishery" (130-200 fathoms or 238-366 m) (Heimann, 1963). Although pelagic when young (Boehlert, 1977), fish greater than 50 mm in length are represented in the benthic habitat. This species associates with mud bottoms and does not enter into the longline or sport catch.

Materials and Methods

All hauls were taken with Nor'Eastern[1] trawls. Otoliths and length-frequency measurements were taken as described in Gunderson and Sample (1980). All lengths reported are fork lengths measured to the nearest centimeter. Length-frequencies were weighted by catch per unit effort (numbers of fish) for the final analysis of size composition. Age was determined from whole otoliths examined under a binocular microscope at ten magnifications using methodology similar to that of Westrheim (1973) and Six and Horton (1977). Each complete hyaline-opaque ring pair was assumed to represent 1 year's growth. Although not verified as true annuli for either species, Westrheim (1973) demonstrated annulus formation in young specimens and was able to follow the progression of a dominant year class through the fishery for Pacific ocean perch. The

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[1]Mention of trade names or commercial products does not imply endorsement by the National Marine Fisheries Service, NOAA.

age-length keys in the current study were applied to weighted length-frequency data to construct age compositions.

Two criteria were applied to determine the geographic and bathymetric units for the analysis of size and age compositions for the two species. The first separation was based on observed differences in growth (from age-length keys); the second was based on differences in the length-frequency distribution by area. The initial units for comparison were divided geographically into areas corresponding roughly to the 13 biological strata (described in Gunderson and Sample, 1980) in the survey and bathymetrically into four depth strata, 50-99 fathoms (91-181 m); 100-149 fathoms (183-272 m); 150-199 fathoms (274-364 m); and 200-260 fathoms (366-475 m). This resulted in 52 possible areas for initial consideration, but data were lacking for many of them.

Results

Canary Rockfish

Totals of 646 otoliths from male and 449 otoliths from female canary rockfish were taken. The mean length for male otolith specimens was 45.5 cm (range 21-61 cm) and for females 47.5 cm (range 21-64 cm). Otoliths were collected from lat. 40°27′N in the south to lat. 48°01′N in the north. Latitudinal growth differences were not examined, however, because 67 percent of all otoliths were taken between lat. 45°32′ and 46°46′N. Age determination from California samples (taken from commercial and recreational catches) shows little latitudinal growth variation for this species (Boehlert[2]).

Numbers of otoliths at each age, mean lengths at age, and standard deviation of length are presented by sex in Table 1. It is apparent from the table that females grow faster than do males beyond age 8-9 and reach a larger size. This phenomenon is frequently observed in other members of the genus *Sebastes* (Six and Horton, 1977; Kelly and Wolf, 1959; and Miller and Geibel, 1973).

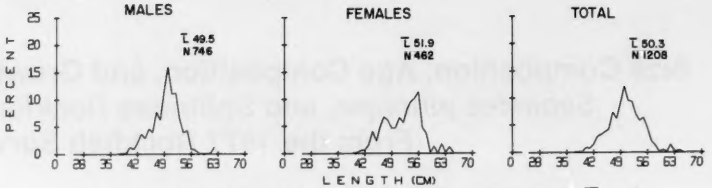

Figure 1.—Size compositions of canary rockfish; mean length ($\bar{L}$) and number of specimens (N) are indicated.

Table 1.—Numbers of otoliths (N), mean lengths (in cm) at age (L), and standard deviation of mean length at age (s) for male and female canary rockfish[1].

Age	Males			Females		
	N	L	s	N	L	s
1	0	—	—	0	—	—
2	0	—	—	0	—	—
3	3	23.0	1.7	3	22.3	1.2
4	8	28.3	3.8	7	29.4	2.9
5	25	31.0	2.2	14	32.9	3.0
6	45	33.3	2.6	27	33.8	2.5
7	18	36.9	1.6	20	37.3	3.5
8	33	42.8	2.2	20	41.4	2.4
9	96	43.5	2.4	57	44.5	2.7
10	87	45.3	2.3	66	46.7	2.2
11	38	46.3	3.1	46	48.0	3.0
12	42	48.8	2.2	23	51.7	2.6
13	63	49.9	1.9	35	53.2	2.0
14	73	50.8	2.2	46	54.5	2.2
15	41	51.0	2.0	42	55.3	2.3
16	37	52.1	2.3	25	56.6	3.5
17	22	53.0	2.6	11	55.1	2.5
18	12	52.6	2.5	6	57.0	3.9
19	3	53.0	1.0	0	—	—
20	0	—	—	1	62.0	0.0

[1]Boehlert, G. W. 1978. Latitudinal growth variation in the genus *Sebastes*. Unpubl. manuscr. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

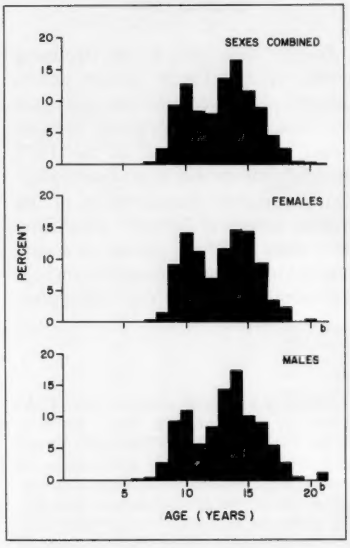

Figure 2.—Age composition of canary rockfish; "b" designates lengths greater than those in the age-length key.

A total of 1,208 length-frequency observations were made on 746 males and 462 females from biological strata 6 to 13. The majority of the observations were made in strata 10 and 11. Of the possible 52 latitudinal and bathymetric areas, length-frequency measurements were made in only 10, representing seven areas in the 50- to 99-fathom (91- to 181-m) range and three areas in the 100- to 149-fathom (183- to 272-m) range. Comparison of the length frequencies from these areas revealed only minor differences in the size compositions, certain of which may have resulted from relatively low sample numbers; consequently, no divisions were made on the basis of length frequencies and the population was considered as a single unit. Size and age composition for the combined collections of canary rockfish are presented in Figures 1 and 2.

Splitnose Rockfish

A total of 1,075 otoliths from male and 751 otoliths from female splitnose rockfish were taken. Although sampling was insufficient to allow bathymetric comparison of growth rates, the otolith collections were widely spaced throughout the 13 biological strata. Three arbitrary latitudinal strata (based

[2] Boehlert, G. W. 1978. Latitudinal growth variation in the genus *Sebastes*. Unpubl. manuscr. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. East, Seattle, WA 98112.

on the collections of otoliths), corresponding to biological strata 1-3, 4-5, and 6-13, were used to analyze latitudinal growth variation. Numbers of otoliths, mean size, and size range of males and females in the otolith collections are presented in Table 2.

Analysis of growth curves indicated that growth rate varies with latitude, being generally faster in the north (Boehlert, footnote 2). Age-length keys from these three strata are presented in Table 3 for both males and females. Due to the differences in growth rate, these three divisions (lat. 34°00′-37°06′, 37°07′-40°25′, and 40°26′-48°30′N) were chosen as latitudinal units for analysis of size and age composition.

A total of 19,436 length-frequency observations were made (10,902 males, 7,632 females, and 902 unsexed) from biological strata 1-13. Of the possible 52 biological and depth strata, length-frequency samples were obtained in 31. These were obtained in 2 of the 50- to 99-fathom (91-181-m) strata, 10 of the 100- to 149-fathom (183- to 272-m) strata, 12 of the 150- to 199-fathom (274- to 364-m) strata, and 7 of the 200- to 260-fathom (366- to 475-m) strata. Comparison of the size compositions in these samples indicates a trend of increasing mean size with depth in a given latitudinal area. Although mean lengths in the two samples in the 50- to 99-fathom range were quite small (14.2 and 12.8 cm), the numbers were relatively low and these depths were represented only in biological strata 1 and 2. For this reason, they were combined with the samples in the 100- to 149-fathom range. Mean lengths and distribution of length frequencies were similar in the 150- to 199- and 200- to 260-fathom ranges but generally differed from the lower mean lengths and length frequency distributions in the 100- to 149-fathom range. Consequently, the samples were divided into shallow (50-149 fathoms; 91-272 m) and deep (150-260 fathoms; 274-475 m) categories.

Size compositions for six latitudinal-bathymetric groups of splitnose rockfish are presented in Figure 3. As is the case with canary rockfish, mean lengths of females are generally greater than those of males. With the exception of the northern stratum (lat. 40°26′-48°30′N), the size compositions in shallow water generally show a broader spread than the more distinct peaks in the deeper water zone. In all three geographic regions, the relative abundance of juveniles (<21 cm) was quite high in the 50- to 149-fathom depth zone, and decreased sharply in the 150- to 260-fathom zone.

Age compositions for splitnose rockfish are presented in Figure 4 (males), Figure 5 (females), and Figure 6 (total). There was insufficient sampling of otoliths in shallow water to allow use of separate age-length keys for the two depth zones; consequently, three male and three female age-length keys (Table 3), based on latitudinal collections of otoliths, were used. Examination of Table 3 indicated that the only complete sampling of young (ages 1-3) fish for otoliths was undertaken in the southern geographic stratum (lat. 34°00′-37°06′N). Relatively large numbers of small specimens, however, were sampled in the length-frequency measurements from the shallow portions of the middle and northern geographic strata (50-149 fathoms, lat. 37°07′-40°25′N and lat. 40°26′-48°30′N: Fig. 3). The lack of young

Table 2.—Number of otoliths, mean size, and size range of specimens of splitnose rockfish by sex and geographic area.

Item	Lat. 34°00′ to 37°06′N		Lat. 37°07′ to 40°25′N		Lat. 40°26′ to 48°30′N	
	Males	Females	Males	Females	Males	Females
No. of otoliths	430	399	339	178	306	174
Mean size (cm)	21.9	23.6	25.4	25.0	27.4	27.6
Size range (cm)	8-32	8-33	14-33	16-36	16-36	16-39

Table 3.—Numbers of otoliths (N), mean lengths at age (L), and standard deviation of mean length (in cm) at age (s) for male and female splitnose rockfish for the three geographic areas[1].

	Lat. 34°00′ to 37°06′N						Lat. 37°07′ to 40°25′N						Lat. 40°26′ to 48°30′N					
	Males			Females			Males			Females			Males			Females		
Age	N	L	s	N	L	s	N	L	s	N	L	s	N	L	s	N	L	s
1	10	8.7	0.7	6	9.3	0.8	0	—	—	0	—	—	0	—	—	0	—	—
2	23	10.8	1.0	26	10.3	1.0	0	—	—	0	—	—	1	16.0	0.0	0	—	—
3	36	12.7	1.1	33	12.9	1.3	2	15.5	2.1	1	16.0	0.0	9	16.2	0.4	9	17.1	0.8
4	19	14.4	1.3	11	13.6	1.3	2	18.0	0.0	6	16.5	0.6	8	18.5	1.5	13	17.8	1.2
5	7	17.3	1.7	5	14.4	1.3	9	18.6	1.5	14	18.9	1.3	17	20.2	1.3	11	20.3	1.4
6	19	17.0	1.9	9	16.7	1.9	18	20.3	1.5	18	19.8	1.2	10	21.0	0.7	10	21.8	1.1
7	15	18.5	2.3	10	19.9	2.8	17	21.4	1.4	15	21.3	0.7	10	21.6	0.8	9	24.1	2.0
8	14	20.8	2.1	9	21.6	1.9	17	22.1	1.9	9	22.1	0.9	4	24.0	0.8	7	24.9	1.3
9	5	22.8	1.5	9	22.3	0.9	18	23.0	1.6	15	24.0	1.1	15	26.1	1.3	5	25.4	1.7
10	17	23.1	1.1	13	22.6	1.1	14	23.4	1.7	14	25.1	1.0	15	26.2	1.2	13	27.1	1.0
11	19	23.1	1.1	15	24.0	1.3	18	24.4	1.0	10	25.4	1.3	10	26.9	1.5	9	27.4	1.5
12	17	24.4	1.3	15	24.7	1.7	21	24.8	1.6	8	26.5	2.0	19	26.6	1.3	5	27.4	1.1
13	33	24.9	1.2	12	25.8	1.7	26	25.7	1.0	6	26.2	1.7	17	27.7	1.4	5	29.8	1.6
14	50	25.1	1.3	26	26.2	1.2	24	26.3	1.5	4	27.8	1.0	20	28.3	1.7	5	30.0	1.6
15	43	26.0	1.4	32	27.2	1.6	35	26.5	1.5	8	28.9	1.6	16	28.4	2.0	13	29.6	1.9
16	28	26.1	1.0	33	27.4	1.5	25	27.1	1.1	7	29.1	1.2	21	29.2	1.7	5	32.0	1.2
17	25	26.7	1.1	45	28.2	1.4	29	27.3	1.4	9	30.0	1.2	29	30.1	1.6	8	32.6	1.3
18	19	26.8	1.4	25	28.4	1.2	18	28.3	1.5	11	29.7	1.1	15	30.2	1.5	7	33.6	3.2
19	12	27.2	2.2	23	29.4	1.5	14	28.6	1.3	6	29.8	1.8	10	30.0	2.0	5	31.4	1.8
20	8	28.0	1.2	18	29.9	1.7	7	29.0	1.6	6	30.0	1.7	15	31.5	2.1	6	34.3	2.2
21	8	27.8	2.1	11	30.6	0.9	6	28.8	1.0	4	31.0	1.2	12	31.5	1.7	8	34.9	2.2
22	2	27.5	2.1	7	30.4	1.0	6	30.3	1.5	2	30.5	2.1	4	32.5	0.6	9	34.3	1.9
23	1	27.0	—	3	30.7	0.6	5	31.4	0.9	2	34.5	2.1	12	31.6	1.2	3	35.3	1.5
24	0	—	—	2	31.0	1.4	3	32.6	0.6	0	—	0.0	5	32.6	1.5	4	34.8	1.0
25	0	—	—	1	33.0	0.0	3	31.0	1.0	2	32.5	0.7	8	31.9	1.2	3	35.0	2.0
26+	0	—	—	0	—	—	2	30.0	1.4	1	35.0	0.0	4	32.5	0.6	2	36.0	2.9

[1]Boehlert, G. W. 1978. Latitudinal growth variation in the genus *Sebastes*. Unpubl. manuscr. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

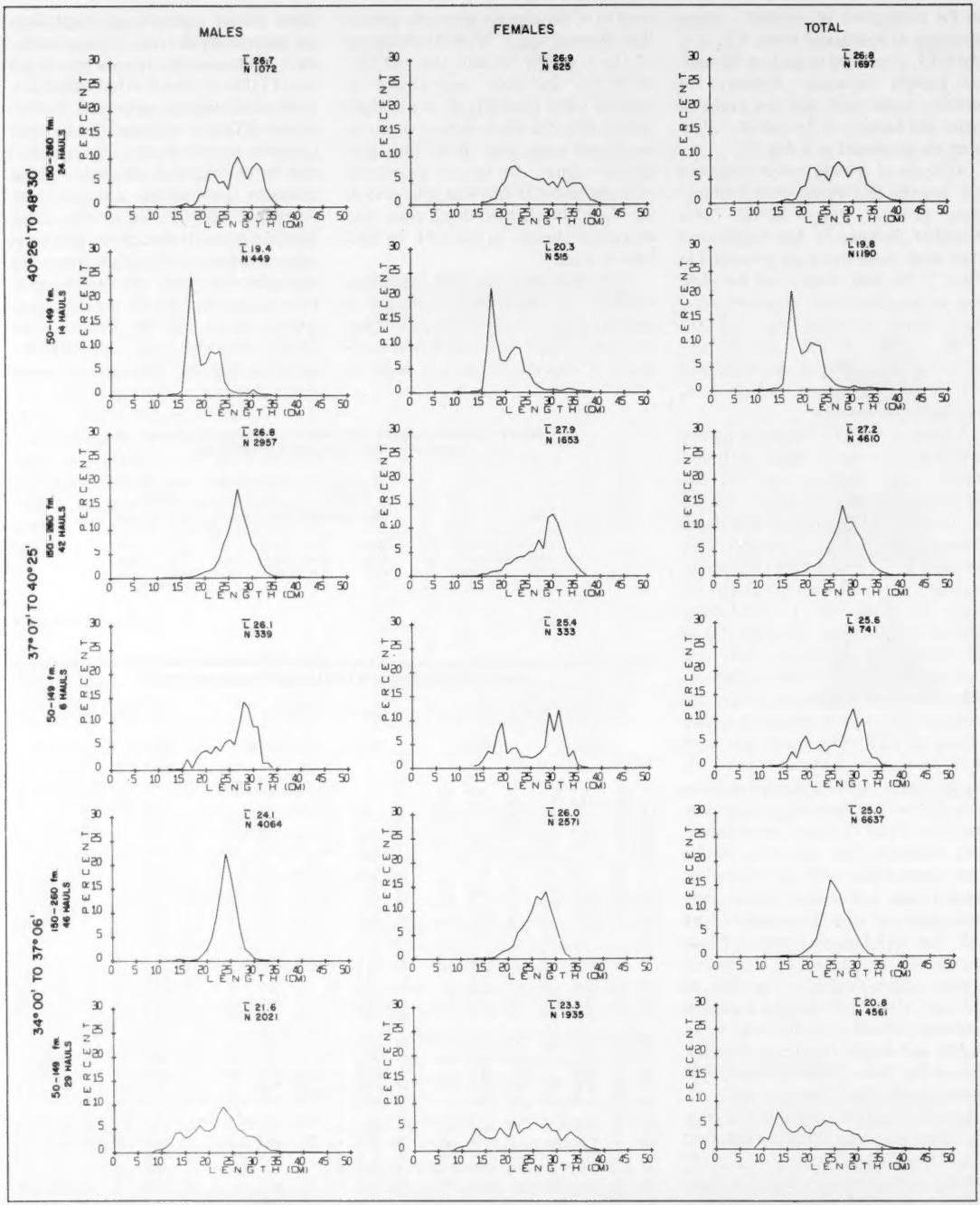

Figure 3.—Size compositions of splitnose rockfish by geographic and bathymetric area. Mean length ($\bar{L}$) and number of specimens (N) are indicated.

specimens in the age-length keys for these areas would have resulted in large proportions of specimens below the key length in the age composition. For this reason, all fish aged 1-3 years were pooled by sex and included in all age-length keys. The inaccuracy involved in assuming similar growth for the first 3 years was compensated for by the information gained in the age compositions.

Discussion

Canary Rockfish

Length frequencies for male canary rockfish showed a dominant mode at 50 cm, whereas those for females were less clear, with a smaller peak at 46-48 cm and a larger peak at 54-56 cm (Fig. 1). Translated to age composition (Fig. 2), there is difficulty in interpreting the point at which recruitment to the sampling gear and area is complete owing in part to the presence of a dominant 1967 year class. The males appear to reach full vulnerability at age 14 (mean length 51 cm), whereas the females reach this stage at age 15 (mean length 55 cm).

Little information exists on the life history and habitat preference of this species. In the southern part of its range, it appears to be primarily a reef-associated species. It composed only 0.2 percent of the rockfish trawl catch off Monterey (Heimann, 1963) but was relatively important in the same area in the partyboat and commercial longline catch over areas generally unsuitable for trawling (Miller and Gotshall, 1965; Miller and Geibel, 1973). In the Columbia region trawl fishery, however, the canary rockfish composes up to 59 percent of the "other rockfish" category at depths from 60 to 90 fathoms (110 to 165 m) (Fraidenburg et al., 1977). Thus, in terms of the fishery, there may be two populations of canary rockfish. At sizes below 50 mm, this species is probably pelagic (Partlo, 1950); subsequent recruitment is probably to the inshore reef population, since juveniles are common in the sport catch (Miller and Gotshall, 1965) and the youngest age classes in the rockfish survey were about 6-7 years (Fig. 2).

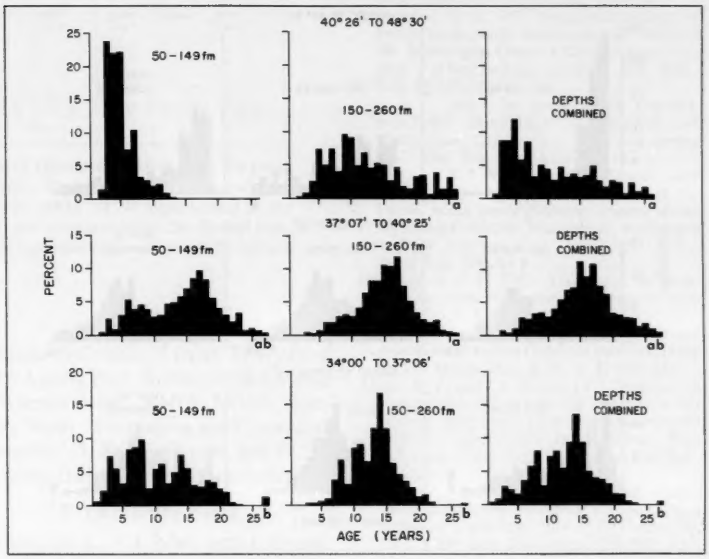

Figure 4.—Age compositions of male splitnose rockfish by area: "a" designates ages greater than 25 years; "b" designates lengths greater than those in the age-length key.

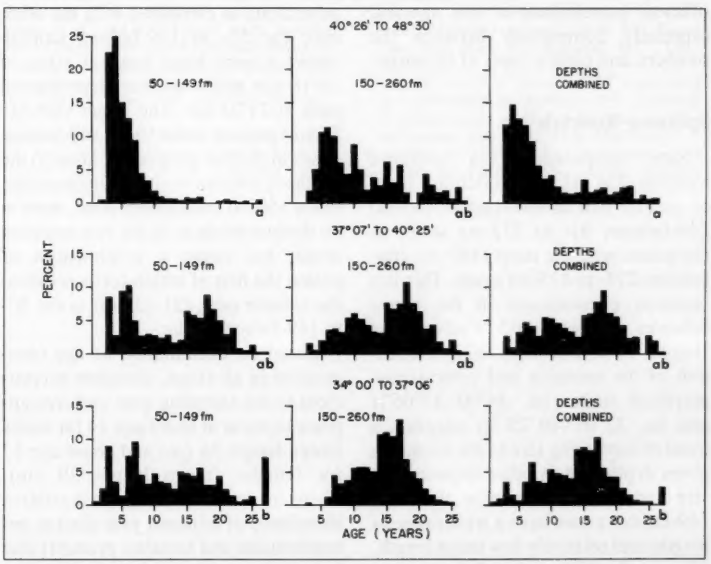

Figure 5.—Age compositions of female splitnose rockfish by area: "a" designates ages greater than 25 years; "b" designates lengths greater than those in the age-length key.

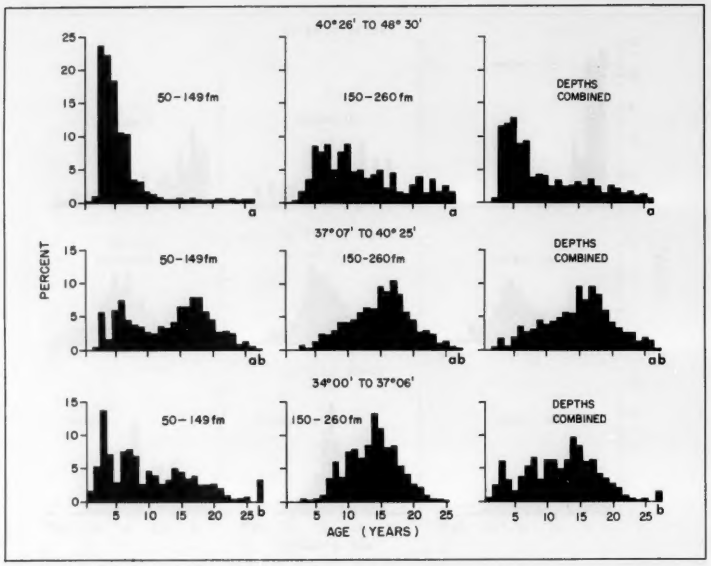

Figure 6.—Age compositions (males, females, and unsexed specimens combined) of splitnose rockfish by area: "a" designates ages greater than 25 years; "b" designates lengths greater than those in the age-length key.

More information is necessary on the relationship between the reef and offshore populations of this species, especially comparison between the southern and central parts of its range.

Splitnose Rockfish

Size compositions for splitnose rockfish (Fig. 3) show a definite trend of smaller fish in the shallow (50- to 149-fathom; 91- to 272-m) strata as compared with the deep (150- to 260-fathom; 274- to 475-m) strata. This is a common phenomenon in the genus *Sebastes* (Moser, 1967; Carlson and Haight, 1976; Boehlert, 1977). Inspection of the southern and central geographical strata (lat. 34°00′-37°06′N and lat. 37°07′-40°25′N) suggests a trend of increasing size to the north at a given depth, but in other respects, the size compositions are similar; the 50- to 149-fathom zones have a wide range of lengths and relatively low mean length, whereas the 150- to 260-fathom strata show well-defined peaks with few specimens in the smaller size categories. The northernmost geographical area (lat. 40°26′-48°30′N) is anomalous as compared with the other two; the 50- to 149-fathom stratum shows a very large peak at sizes of 16-18 cm and a smaller, less distinct peak at 21-23 cm. The larger sizes (to 35 cm) present in the 50- to 149-fathom zones in the two geographic areas to the south are not represented. Furthermore, in the 150- to 260-fathom zone, there is no distinct mode as in the two southern strata, but rather a combination of peaks, the first of which corresponds to the smaller peak (21-23 cm) in the 50- to 149-fathom range.

Based on examination of age composition in all strata, complete recruitment to the sampling gear and area appears to occur at about age 14 for males (mean length 26 cm) and about age 17 for females (mean length 29 cm). There are definite differences in relative abundance of adjacent year classes between males and females, probably due to sampling errors and the use of age-length keys. For most strata, however, the general form of the age frequency distribution was quite comparable between sexes (Fig. 4, 5).

In the southernmost geographic stratum, the 50- to 149-fathom (91- to 272-m) zone has a large proportion of fish aged 10 or less, but considerable numbers of older individuals are also present. In the central geographic stratum, fish aged 15-18 make up a major part of the population in both depth zones. In both of these areas, the 150- to 260-fathom (274- to 475-m) zone is dominated by older fish. As with size composition, age composition in the northern geographic stratum is considerably different from the central and southern strata. In the 50- to 149-fathom zone, fish beyond age 12 are rare, and age composition in the 150- to 260-fathom zone is similar to the shallow zone in the southernmost geographic stratum (Fig. 4-6).

I interpret the size and age composition in the northern geographic area (lat. 40°26′-48°30′N) to be the result of fishing pressure. Unfortunately, historical fishing information on members of the "other rockfish" group is relatively scanty. The best data available on the size composition of splitnose rockfish prior to the present study are those of Alverson et al. (1964). Length-frequencies of 672 specimens from the Washington-Oregon region (taken in 1961-62) are plotted in Figure 7 against those from lat. 40°26′-48°30′N (depths combined) in the 1977 rockfish survey. The data from the previous study show a continuation of the trend which would be expected in deep water—i.e., a distinct peak in the size composition similar to the deep southern samples and an increase in the mean length. The current data show a shift to smaller sizes than would be expected, as is evident in both the size and age composition.

The splitnose rockfish commands a relatively low market price and is only partially vulnerable to commercial trawling off Oregon-California where cod end mesh size must be 4.5 inches (11.4 cm) or greater; consequently, there has generally been no directed fishery for this species except in certain areas of very high abundance (Heimann, 1963). Off California, it was an important component of the

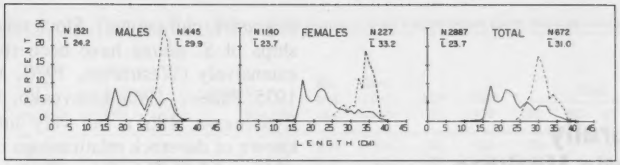

Figure 7.—Comparison of size composition of splitnose rockfish from the present study with that from Alverson et al. (1964). Data from the present study are from all depths in the northern area (lat. 40°26′ to 48°30′N), represented by the solid line; data from Alverson et al. (1964) are represented by the dashed line. Mean length ($\bar{L}$) and number of specimens (N) are indicated; values on the left are from the present study.

animal food fishery in the early 1960's (Nitsos and Reed, 1965). In the north, however, the species is most closely associated with catches of Pacific ocean perch (Alverson and Westrheim, 1961); the remarkable decline of the Pacific ocean perch stocks in the Oregon-Washington region has been well documented (Gunderson, 1977; Gunderson et al., 1977). Although no data on the incidental catch of splitnose rockfish in the foreign and domestic catch of Pacific ocean perch are available, it is likely that the close ecological association of these two species may have resulted in a concomitant decline in the northern stocks of splitnose rockfish, a slow-growing, long-lived species which is probably unable to withstand intensive fishing pressure.

Acknowledgments

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Literature Cited

Alverson, D. L., A. T. Pruter, and L. L. Ronholt. 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. H. R. MacMillan Lectures in Fisheries. Inst. Fish., Univ. Brit. Columbia, Vancouver, B.C., 190 p.

_____, and S. J. Westrheim. 1961. A review of the taxonomy and biology of the Pacific ocean perch and its fishery. Rapp. P-V Réun. Cons. Int. Explor. Mer 150:12-27.

Boehlert, G. W. 1977. Timing of the surface-to-benthic migration in juvenile rockfish, *Sebastes diploproa*, off southern California. Fish. Bull., U.S. 75:887-890.

Carlson, H. R., and R. E. Haight. 1976. Juvenile life of Pacific ocean perch, *Sebastes alutus*, in coastal fiords of southeastern Alaska: Their environment, growth, food habits, and schooling behavior. Trans. Am. Fish. Soc. 105:191-201.

Fraidenburg, M., J. E. Smith, W. H. Barss, and T. Jow. 1977. Minimum estimates of the all nation removals, North American trawl species composition and CPUE for "other rockfish" in the northeastern Pacific Ocean. Wash. Dep. Fish., Tech. Rep. 34, 31 p.

Gunderson, D. R. 1977. Population biology of Pacific ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte Sound region, and their response to fishing. Fish. Bull., U.S. 75:369-403.

_____, and T. M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev. 42(3-4):2-16.

_____, S. J. Westrheim, R. L. Demory, and M.E. Fraidenburg. 1977. The status of the Pacific ocean perch (*Sebastes alutus*) stocks off British Columbia, Washington, and Oregon in 1974. Environ. Can., Fish. Mar. Serv., Tech. Rep. 690, 63 p.

Heimann, R. F. G. 1963. Trawling in the Monterey Bay area, with special reference to catch composition. Calif. Fish Game 49:152-173.

Kelly, G. F., and R. S. Wolf. 1959. Age and growth of the redfish (*Sebastes marinus*) in the Gulf of Maine. Fish. Bull., U.S. 60:1-31.

Miller, D. J., and J. J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study, and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Calif. Dep. Fish Game, Fish Bull. 158, 137 p.

_____, and D. Gotshall. 1965. Ocean sportfish catch and effort from Oregon to Point Arguello, California, July 1, 1957-June 30, 1961. Calif. Dep. Fish Game, Fish Bull. 130, 135 p.

_____, and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game, Fish Bull. 157, 235 p.

Moser, H. G. 1967. Reproduction and development of *Sebastodes paucispinis* and comparison with other rockfishes off southern California. Copeia 1967:773-797.

Nitsos, R. J., and P. H. Reed. 1965. The animal food fishery in California, 1961-1962. Calif. Fish Game 51:16-27.

Partlo, J. M. 1950. A report on the 1949 albacore fishery (*Thunnus alalunga*). Fish. Res. Board Can., Pac. Biol. Stn. Nanaimo, B.C., Circ. 20, 37 p.

Six, L. D., and H. F. Horton. 1977. Analysis of age determination methods for yellowtail rockfish, canary rockfish, and black rockfish off Oregon. Fish. Bull., U.S. 75:405-414.

Westrheim, S. J. 1973. Age determination and growth of Pacific ocean perch (*Sebastes alutus*) in the northeast Pacific Ocean. J. Fish. Res. Board Can. 30:235-247.

Stock Separation of Five Rockfish Species Using Naturally Occurring Biochemical Genetic Markers

LISA N. WISHARD, FRED M. UTTER, and DONALD R. GUNDERSON

ABSTRACT–Stock relationships of five commercially important rockfish (genus Sebastes*) species were studied using biochemical genetic information developed through electrophoresis. Samples of Pacific ocean perch,* S. alutus*, were collected off Washington and Oregon and in the Gulf of Alaska from Dixon Entrance to Kodiak. Three stock groups were recognized for Pacific ocean perch. One exists off the Washington and Oregon coasts, while another is found in the Gulf of Alaska. A third previously unrecognized stock was tentatively identified off Prince William Sound. Samples of canary rockfish,* S. pinniger*; yellowtail rockfish,* S. flavidus*; chilipepper,* S. goodei*; and bocaccio,* S. paucispinis*, were collected off the California, Oregon, and Washington coasts. Two stocks may exist for canary rockfish–one located off northern California and southern Oregon and the other located off northern Oregon and Washington. Only one stock group per species was recognized for yellowtail rockfish, chilipepper, and bocaccio. The relationship of the different species to each other and the general applications of the techniques of electrophoresis to work in marine fisheries are also discussed.*

Introduction

Biochemical genetics has gained increasingly widespread acceptance as a stock separation tool during the last decade. The analytical techniques of biochemical genetic (i.e., electrophoretic) studies are based on the distributions among individuals and populations of simple genetic protein variants. These variants, which have been shown to be coded for by single genes, are inherited according to simple genetic principles, remain unchanged throughout the life of the organism, and are passed on from generation to generation (Utter et al., 1974). A significant difference between biochemical genetic techniques and the traditional types of stock separation techniques is that the biochemical techniques detect only genetic differences. Genetic and environmental influences may not be distinguishable by traditional methods such as meristic studies, size distribution, or year-class strength comparisons. However, the two approaches, biochemical and traditional, can be valuable complements to each other.

Electrophoretic data allow a population or a species to be characterized by its frequency of biochemical genetic variants. Groups of individuals which share a common gene pool will have similar gene frequencies for these variants. However, if isolation between groups occurs, these frequencies may shift either by natural selection or such random processes as genetic drift, and the isolates may develop significantly different gene frequencies. These gene frequency differences can be used as an effective stock separation tool to identify noninterbreeding groups.

This report presents the findings of the biochemical genetic data collected in conjunction with the 1977 rockfish survey. The primary focus concerned *Sebastes alutus,* Pacific ocean perch, but significant amounts of data were also collected from four of the other rockfish species (*S. pinniger,* canary rockfish; *S. flavidus,* yellowtail rockfish; *S. paucispinis,* boccacio; and *S. goodei,* chilipepper). Stock relationships of *S. alutus* have been studied extensively (Westrheim, 1970, 1973, 1975; Fadeev, 1968; Lisovenko, 1964; Lyubimova, 1965), but very little is known of the stock relationships of the other rockfish. This paper compares the genetic data with the previously published stock relationships of *S. alutus* and outlines possible stock relationships based solely on genetic data for the other four species. The genetic relationships among the five species are also investigated. In addition, the role of genetic studies in the management of rockfish and other marine fisheries is discussed.

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Methods and Materials

Samples for electrophoresis were collected on board ship concurrently with the collection of other rockfish data and samples. Approximately 10 g of muscle and liver tissue were extracted from each fish, placed in a 4- × 4-inch Ziploc[1] bag, identified by specimen number, and frozen as soon as possible. Sex and length data were taken on each fish; in some cases weight data and otoliths were also taken. Each fish could then be identified by genotype, sex and length (and by weight and age when available). All fish from an individual haul were combined and identified by a vessel and haul number (Tables 1-5).

Sampling was designed to include 50 fish from three different depth zones within each stratum of the major distributional areas of a particular species. However, in practice the genetic samples were collected whenever an adequate number of fish were caught in a particular haul. As a result the sampling localities are heavily concentrated in the areas of maximum abundance. Not all depth zones nor strata are represented for each species. The size of the confidence intervals around the gene frequency estimates is a direct function of the number of fish examined according to the following formula:

[1]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Allele frequencies for Pacific ocean perch, *Sebastes alutus*, collected during 1977.

Stratum	Vessel and haul number	Depth (fm)	Location		Mo. and day	Sample size	AGP	PGM	PGI-2				6PG	ADH					IDH-2			
			N. Lat.	W. Long.			100	100	100	92	87	79	100	100	66	46	110	164	100	80	68	120
8	23-094	95	43°50′	124°51′	8-23	49	.52	.52	1.00	—	—	—	.99	.99	—	—	—	.01	1.00	—	—	—
8	23-090	140	43°09′	124°45′	8-21	49	.68	.43	1.00	—	—	—	.97	.96	.03	—	.01	—	.99	—	—	.01
9	23-097	112	44°08′	124°57′	8-24	50	.58	.41	1.00	—	—	—	.97	.97	.03	.01	—	—	—	—	—	—
9	22-167	117	44°53′	124°28′	9-01	48	.60	.42	1.00	—	—	—	.98	.95	.03	.01	.01	—	.99	—	—	.01
10	22-179	112	45°14′	124°18′	9-06	50	.58	.38	.96	.04	—	—	.96	.97	.03	—	—	—	1.00	—	—	—
10	22-172	114	45°04′	124°20′	9-05	50	.55	.49	1.00	—	—	—	.98	.97	.03	—	—	—	.99	—	.01	—
10	04-203	120	45°00′	124°22′	9-01	20	.47	.55	1.00	—	—	—	.95	.97	.03	—	—	—	1.00	—	—	—
10	23-105	127	45°13′	124°21′	8-27	49	.68	.49	1.00	—	—	—	.97	.99	.01	—	—	—	1.00	—	—	—
10	23-107	165	45°25′	124°27′	8-28	49	.58	.51	1.00	—	—	—	.98	.98	—	—	.02	—	1.00	—	—	—
10	23-104	190	45°07′	124°33′	8-27	46	.61	.43	1.00	—	—	—	.97	.97	.03	—	—	—	.99	—	.01	—
10	04-209	203	45°11′	124°35′	9-05	15	.47	.55	1.00	—	—	—	.95	.97	.03	—	—	—	1.00	—	—	—
10	04-210	214	45°10′	124°31′	9-05	22	.80	.36	1.00	—	—	—	.98	1.00	—	—	—	—	1.00	—	—	—
10	04-208	222	45°02′	124°41′	9-05	13	.61	.46	1.00	—	—	—	.88	.96	.04	—	—	—	.96	—	.04	—
11	04-222	102	46°18′	124°37′	9-08	50	.59	.47	1.00	—	—	—	.96	.99	.01	—	—	—	1.00	—	—	—
11	22-186	105	46°26′	124°32′	9-08	50	.60	.40	.99	—	—	.01	1.00	.96	.02	.01	.01	—	.99	.01	—	—
11	22-191	106	46°36′	124°37′	9-09	48	.64	.40	1.00	—	—	—	.98	.97	.02	—	.01	—	1.00	—	—	—
11	20-014	118	45°53′	124°41′	9-01	47	.67	.46	1.00	—	—	—	1.00	.96	.04	—	—	—	1.00	—	—	—
11	22-192	150	46°36′	124°37′	9-09	43	.59	.53	1.00	—	—	—	.97	.89	.07	.02	—	.02	1.00	—	—	—
11	22-187	158	46°26′	124°33′	9-08	50	.70	.54	1.00	—	—	—	.98	.98	.01	—	.01	—	1.00	—	—	—
11	20-013	209	45°54′	124°45′	9-01	14	.61	.40	1.00	—	—	—	.93	.89	.07	—	.04	—	.92	—	.04	.04
11	23-113	211	45°54′	124°46′	8-29	20	.60	.50	1.00	—	—	—	.90	1.00	—	—	—	—	1.00	—	—	—
12	04-234	172	46°49′	124°54′	9-14	49	.56	.42	1.00	—	—	—	.99	.99	.01	—	—	—	1.00	—	—	—
12	04-241	222	47°13′	124°56′	9-15	47	.69	.51	1.00	—	—	—	.94	.97	.03	—	—	—	1.00	—	—	—
12	22-203	225	47°10′	124°59′	9-15	20	.47	.55	1.00	—	—	—	.95	.97	.03	—	—	—	1.00	—	—	—
13	04-251	70	48°21′	124°57′	9-18	41	.59	.44	1.00	—	—	—	.99	.97	.02	—	—	.01	1.00	—	—	—
13	23-132	96	48°13′	124°58′	9-04	32	.64	.47	1.00	—	—	—	.98	.97	.03	—	—	—	1.00	—	—	—
13	23-128	106	47°50′	125°08′	9-21	50	.49	.44	1.00	—	—	—	.95	.99	.01	—	—	—	1.00	—	—	—
13	23-134	115	48°19′	125°52′	9-04	49	.54	.41	1.00	—	—	—	.99	.98	.02	—	—	—	1.00	—	—	—
13	22-209	118	47°11′	124°35′	9-05	14	.68	.60	1.00	—	—	—	.90	.83	.17	—	—	—	1.00	—	—	—
13	23-131	121	47°59′	125°37′	9-03	50	.49	.48	1.00	—	—	—	.98	1.00	—	—	—	—	1.00	—	—	—
13	22-220	168	47°53′	125°14′	9-22	50	.57	.40	1.00	—	—	—	.99	.97	.03	—	—	—	1.00	—	—	—
13	04-267	172	48°09′	125°42′	9-22	50	.54	.43	1.00	—	—	—	.99	.96	.02	—	—	.01	.99	—	.01	—
13	23-125	180	47°35′	125°05′	9-02	51	.66	.35	1.00	—	—	—	.90	.94	.04	—	—	.01	.99	—	.01	—
13	04-268	229	48°10′	125°43′	9-22	50	.65	.40	1.00	—	—	—	.93	.95	.05	—	—	—	.98	—	—	.02
17	23-011	87	56°60′	136°06′	7-08	48	.65	.50	1.00	—	—	—	1.00	.95	.04	—	—	—	.95	—	—	.04
17	23-016	104	57°59′	137°51′	7-10	46	.59	.48	1.00	—	—	—	1.00	.98	.02	—	—	—	1.00	—	—	—
19	23-026	175	59°10′	141°15′	7-14	24	.56	.55	1.00	—	—	—	.98	.98	.02	—	—	—	.98	—	.02	—
19	23-032	156	59°37′	143°05′	7-16	48	.62	.55	1.00	—	—	—	1.00	.94	.06	—	—	—	.97	.01	.01	—
20	23-056	109	59°14′	147°39′	7-25	49	.46	.48	.99	—	.01	—	1.00	.85	.15	—	—	—	.99	—	.01	—
20	23-055	103	59°05′	147°54′	7-27	18	.42	.39	.97	—	.03	—	1.00	.97	.03	—	—	—	.97	—	.03	—
20	23-1000	—	—	—	7-00	50	.38	.54	.98	—	.02	—	1.00	.89	.09	.02	—	—	.99	—	.01	—
21	23-049	70	59°53′	149°07′	7-25	49	.50	.61	1.00	—	—	—	1.00	.96	.04	—	—	—	.99	—	.01	—

95% Confidence interval $= \pm 2$ SE

$$= 2\sqrt{\frac{p\,(1-p)}{2N}}$$

where N is the number of fish, p is the frequency of the allele in question, and $(1-p)$ is the combined frequency of all other alleles at that locus. An attempt was made to collect 50 fish from each haul to obtain reasonable confidence intervals around the estimates, but in many cases this was not possible since fewer than 50 fish were caught.

Sampling was most intensive for Pacific ocean perch. A total of 1,385 fish were taken off the Oregon and Washington coasts. An additional 400 fish were collected in the Gulf of Alaska aboard the Polish research vessel *Profesor Siedlecki* (Stratum 14-21, Table 6). Fewer individuals of the other four species were captured. Samples were taken from a total of 620 canary rockfish, 593 yellowtail rockfish, 506 chilipepper, and 327 bocaccio. (See Tables 1-5 for sampling localities.)

Samples were shipped frozen to the Northwest and Alaska Fisheries Center of the National Marine Fisheries Service (NMFS) in Seattle, Wash., for analysis. Electrophoresis was conducted following the methods of Utter et al. (1974). During electrophoresis, the various proteins were subjected to an electric current and migrated different distances through a starch gel according to their relative charge and structure. After electrophoresis, histochemical staining techniques described in Allendorf et al. (1977) were used to visualize the proteins.

For each electrophoretically detectable locus the mobility (distance travelled) of the most common protein type found in Pacific ocean perch was used as a standard. The mobility of all other variants or alleles for any of the rockfish

Table 2.—Allele frequencies for canary rockfish, *Sebastes pinniger*, collected during 1977.

Stratum	Vessel and haul number	Depth (fm)	Location N. Lat.	Location W. Long.	Mo. and day	Sample size	PGM 100	PGI-2 100	PGI-2 87	PGI-2 79	PGI-2 69	ME-1 100	ME-1 65	ME-1 96	TO 100	TO 25	TO 66	SDH 100	SDH 50	IDH-1 100	ME-2 100	ME-2 110	ME-2 93
6	25-065	64	40°27′	124°35′	8-13	50	.93	—	.98	—	.02	.93	.07	—	1.00	—	—	1.00	—				
6	23-081	78	40°58′	124°22′	8-18	28	.86	.02	.93	—	.05	.91	.09	—	1.00	—	—	.98	.02	1.00	1.00	—	—
7	23-088	47	42°50′	124°40′	8-21	14	.89	—	1.00	—	—	1.00	—	—	1.00	—	—	1.00	—	1.00	1.00	—	—
7	23-089	78	42°59′	124°48′	8-21	50	.88	.02	.96	—	.02	.94	.06	—	.99	—	.01	1.00	—	1.00	1.00	—	—
8	23-091	115	43°25′	124°40′	8-22	50	.87	—	.97	—	.03	.88	.11	.01	1.00	—	—	1.00	—	1.00			
9	23-100	82	44°35′	124°33′	8-25	50	.92	—	.99	—	.01	.93	.07	—	.99	—	.01	1.00	—	1.00	.98	—	.02
9	04-192	92	44°24′	124°46′	8-29	18	.85	—	.94	.03	.03	1.00	—	—	1.00	—	—	1.00	—	1.00	1.00	—	—
10	20-009	101	45°50′	124°38′	9-01	42	.92	—	.99	—	.01	.87	.13	—	1.00	—	—	.99	.01	1.00	1.00	—	—
11	23-116	46	46°12′	124°17′	8-30	50	.85	.03	.94	.01	.02	.91	.08	.01	1.00	—	—	1.00	—	1.00	.98	.02	—
11	04-225	65	46°21′	124°26′	9-08	50	.88	.02	.98	—	—	.91	.09	—	1.00	—	—	1.00	—	1.00			
11	23-118	69	46°34′	124°29′	8-30	28	.87	—	.95	—	.05	.91	.09	—	1.00	—	—	1.00	—	.98	.98	.02	—
11	22-191	106	46°36′	124°37′	9-09	35	.89	—	.99	.01	—	.94	.06	—	1.00	—	—	—	—	.99	1.00	—	—
12	23-120	44	46°46′	124°26′	8-31	50	.78	—	1.00	—	—	.94	.06	—	.99	.01	—	1.00	—	1.00	.99	—	.01
12	04-243	110	47°29′	124°53′	9-16	33	.95	.02	.95	.01	.02	.88	.12	—	1.00	—	—	1.00	—	.98	1.00	—	—
13	23-129	85	47°59′	125°12′	9-03	22	.95	—	1.00	—	—	.88	.12	—	1.00	—	—	1.00	—	1.00	1.00	—	—
13	22-231	88	48°01′	125°28′	9-25	50	.86	—	.98	—	.02	.93	.07	—	1.00	—	—	1.00	—	.99	1.00	—	—

Table 3.—Allele frequencies for yellowtail rockfish, *Sebastes flavidus*, collected during 1977.

Stratum	Vessel and haul number	Depth (fm)	Location N. Lat.	Location W. Long.	Mo. and day	Sample size	PGI-2 87	PGI-2 105	PGI-2 69	6PG 100	6PG 95	6PG 107	6PG 125	MDH-1 110	MDH-1 100	PEP-2 105	IDH-1 100	IDH-1 80	IDH-1 89	IDH-2 100	IDH-2 110	IDH-2 120	IDH-2 86
7	22-135	55	42°52′	124°41′	8-23	39	1.00	—	—	—	.64	.33	.03	—	.99	.88	1.00	—	—	.99	—	—	.01
7	23-089	78	42°59′	124°48′	8-21	50	1.00	—	—	—	.62	.37	—	.01	.99	.86	1.00	—	—	1.00	—	—	—
7	25-017	80	42°34′	124°42′	8-05	50	1.00	—	—	—	.53	.47	—	—	.99	.86	.99	.01	—	.94	—	—	.06
9	22-169	69	44°50′	124°18′	9-02	50	1.00	—	—	—	.46	.53	—	.01	.99	.90	1.00	—	—	.98	—	.01	.01
9	22-159	80	44°34′	124°34′	8-31	50	.99	.01	—	—	.58	.42	—	—	.98	.90	1.00	—	—	1.00	—	—	—
11	23-116	46	46°12′	124°17′	8-30	37	.99	.01	—	—	.55	.44	.01	—	.98	.85	.99	.01	—	1.00	—	—	—
11	22-190	54	46°37′	124°26′	9-08	38	1.00	—	—	—	.49	.51	—	—	1.00	.91	.99	—	.01	1.00	—	—	—
11	04-222	102	46°18′	124°37′	9-08	50	1.00	—	—	.01	.63	.35	.01	—	1.00	.92	1.00	—	—	.98	—	—	.02
11	23-118	69	46°34′	124°29′	8-30	50	1.00	—	—	—	.55	.44	—	.01	1.00	.82	1.00	—	—	.99	.01	—	—
12	04-244	86	47°30′	124°52′	9-16	50	1.00	—	—	—	.61	.39	—	—	.98	.90	1.00	—	—	.96	—	—	.04
12	04-239	129	47°13′	124°54′	9-15	48	.98	—	.02	—	.65	.35	—	—	1.00	.91	1.00	—	—	1.00	—	—	—
13	04-258	61	48°16′	124°54′	9-21	31	1.00	—	—	.02	.46	.50	.02	—	1.00	—	1.00	—	—	.98	—	—	.02
13	04-260	66	48°15′	125°06′	9-21	50	1.00	—	—	—	.60	.40	—	—	.99	.90	1.00	—	—	.99	—	—	.01

Table 4.—Allele frequencies for bocaccio, *Sebastes paucispinis*, collected during 1977.

Stratum	Vessel and haul number	Depth (fm)	Location N. Lat.	Location W. Long.	Mo. and day	Sample size	PGM 100	PGI-1 100	PGI-2 87	ADH 46	IDH-1 100
1	04-011	100	34°13′	119°43′	7-06	32	1.00	0.58	1.00	0.55	1.00
2	22-011	62	34°49′	120°48′	7-15	50	0.99	0.51	0.98	0.63	0.97
3	22-045	95	36°25′	121°60′	7-21	50	0.99	0.60	0.98	0.58	1.00
4	04-130	69	38°12′	123°18′	8-03	12	1.00	0.59	1.00	0.54	1.00
5	22-110	80	39°08′	123°56′	8-08	28	0.98	0.62	1.00	0.53	1.00
5	22-125	94	39°42′	123°59′	8-11	21	1.00	0.69	1.00	0.68	1.00
5	23-073	96	39°13′	123°57′	8-16	27	1.00	0.50	1.00	0.59	0.98
5	23-078	98	40°04′	124°15′	8-17	57	0.99	0.54	0.98	0.51	1.00
7	23-089	78	42°59′	124°48′	8-21	50	0.97	0.55	1.00	0.57	1.00

species was calculated relative to this common allelic form of Pacific ocean perch which was designated with a mobility of 100. An allelic protein that migrated half as far as the common protein would be designated 50. In the case of multiple forms of the same enzyme, a hyphenated number is attached to the protein abbreviation. A list of the 21 routinely scored loci for the rockfish population survey is given in Table 7 (along with the abbreviation) and the tissue in which the locus was best resolved.

Average genetic heterozygosity ($\bar{H}$) or the average proportion of the genome heterozygous per individual (Selander and Johnson, 1973) was estimated for each of the five species by the formula

$$\bar{H} = (L - \sum_{i=1}^{L} \sum_{j=1}^{A_i} p_{ij}^2) / L$$

where L is the number of loci examined, A_i is the number of alleles at a particular locus, and P_{ij} is the frequency of the jth allele at the ith locus. This is a good measure of the amount of total genetic variation found within a population or a species.

To quantify the relationships between species, similarity coefficients (S) (Rogers, 1972) were calculated between all pairs of species. The coefficient is defined as

$$S = 1 - \frac{1}{L} \sum_{i=1}^{L} \left[\tfrac{1}{2} \sum_{j=1}^{A_i} (p_{ijx} - p_{ijy})^2 \right]^{1/2}$$

where L is the number of loci, A_i is the number of alleles at the ith locus, and p_{ijx} and p_{ijy} are the frequencies of the jth allele at the ith locus in species x and y, respectively. The index ranges from one (for identical allele frequencies) to zero (for those which have no alleles shared in common). These values were used to construct a dendrogram using standard numerical taxomonic techniques (Sneath and Sokal, 1973).

Results and Discussion

Genetic Data For Each Species

This report mainly concerns geographic variation of gene frequencies, although other patterns of variation were also considered. Clines of gene frequencies with depth were investigated to test if gene frequencies could be significantly correlated with depth. No such clines were found for any species at any locus. Age data from otolith readings were available for certain Pacific ocean perch samples from fish taken by the *Profesor Siedlecki*. These data were used to examine the possibility that genotype frequencies varied significantly with age. Again no such relationships were found. Further analyses showed no significant differences between sexes where those data were available.

The collected gene frequencies for each haul examined were tested against the Hardy-Weinberg equilibrium. Significant deviations from the expected values could indicate random sampling errors, an incorrect genetic model for a particular locus, some type of selection, or a mixture of noninterbreeding populations. No consistent significant deviations were detected at any locus for any species.

Pacific Ocean Perch

Pacific ocean perch was the most variable of all the species studied, with a heterozygosity value equal to 0.060. This value is approximately equal to the

Table 5.—Allele frequencies for chilipepper, *Sebastes goodei*, collected during 1977.

Stratum	Vessel and haul number	Depth (fm)	Location N. Lat.	Location W. Long.	Mo. and day	Sample size	6PG 107	6PG 110	6PG 104	PGM 100	PGI-2 87	PGI-2 100	PGI-2 105
1	04-018	56	34°07′	119°57′	7-08	15	.97	—	.03	1.00	.98	.01	.01
2	22-005	58	34°40′	120°48′	7-14	50	.97	.01	.02	1.00	1.00	—	—
2	22-006	108	34°40′	120°51′	7-14	50	.98	.01	.01	.98	1.00	—	—
2	04-046	120	34°27′	120°39′	7-13	24	.98	—	.02	1.00	1.00	—	—
3	04-098	56	36°51′	122°06′	7-22	44	.98	—	.01	1.00	.98	—	.01
3	22-050	100	36°52′	122°12′	7-22	50	.98	—	.02	1.00	1.00	—	—
3	04-096	178	36°48′	122°08′	7-22	16	1.00	—	—	1.00	1.00	—	—
4	04-113	62	37°59′	123°19′	7-31	37	.97	—	.03	.98	1.00	—	—
4	04-133	110	38°24′	123°33′	8-04	25	.96	—	.04	1.00	1.00	—	—
4	22-100	120	38°46′	123°50′	8-06	34	.98	—	.02	1.00	1.00	—	—
4	04-123	124	38°04′	123°31′	8-01	49	.95	—	.05	1.00	1.00	—	—
4	04-124	175	38°04′	123°32′	8-02	12	1.00	—	—	1.00	1.00	—	—
5	22-113	89	39°29′	123°58′	8-09	50	.98	.02	—	.99	.98	.01	.01
5	23-078	98	40°04′	124°15′	8-17	50	.98	—	.01	1.00	1.00	—	—

Table 6.—Boundaries for the geographic areas.

Geographic stratum	Latitudinal (N) boundaries	Geographic stratum	Latitudinal (N) boundaries	Geographic stratum	Latitudinal (N) boundaries
1	34°09′-34°30′	9	44°08′-45°00′	17	56°00′-58°00′
2	34°30′-36°00′	10	45°00′-45°50′		
3	36°16′-37°07′	11	45°50′-46°44′		Longitudinal (W) boundaries
4	37°07′-38°49′	12	46°44′-47°30′		
5	38°49′-40°16′	13	47°30′-48°26′	18	136°00′-140°00′
6	40°25′-41°47′	14	48°26′-52°00′	19	140°00′-144°00′
7	41°47′-43°00′	15	52°00′-54°00′	20	144°00′-148°00′
8	43°00′-44°08′	16	54°00′-56°00′	21	148°00′-152°00′

Table 7.—A list of the enzymes, their abbreviations, and the tissues routinely screened for variation in all five of the *Sebastes* species. Since different genes may code for the same product, each is given a numerical indentifier which follows the abbreviation; i.e., IDH-2 is the second locus coding for isocitrate dehydrogenase.

Enzyme	Abbreviation	Best tissue
Alcohol dehydrogenase	ADH	Liver
Aspartate aminotransferase	AAT	Liver
Creatine kinase	CK	Muscle
Beta-glucuronidase	BGD	Liver
Alpha-glycerophosphate dehydrogenase	AGP	Muscle
Isocitrate dehydrogenase	IDH-1	Muscle
	IDH-2	Liver
Lactate dehydrogenase	LDH	Muscle
Malate dehydrogenase	MDH-1	Muscle
	MDH-2	Muscle
Malic enzyme	ME-1	Muscle
	ME-2	Muscle
Peptidase	PEP-1	Muscle
	PEP-2	Muscle
6-phosphogluconate dehydrogenase	6PG	Muscle
Phosphoglucomutase	PGM	Muscle
Phosphoglucose isomerase	PGI-1	Muscle
	PGI-2	Muscle
Phosphomannose isomerase	PMI	Muscle
Sorbitol dehydrogenase	SDH	Liver
Tetrazolium oxidase	TO	Liver

average for all vertebrate species (Selander and Johnson, 1973). Previously only two biochemical genetic variants had been reported in the literature. These were the AGP (alpha-glycerophosphate dehydrogenase) and PGM (phosphoglucose mutase) loci (Johnson et al., 1972). In this study genetic polymorphisms were found at 15 loci. Four of the 15 polymorphic loci showed variant frequencies that were useful in population characterization: 6PG (6-phosphoglucose dehydrogenase), ADH (alcohol dehydrogenase), PGI-2 (phosphoglucose isomerase-2), and IDH-2 (isocitrate dehydrogenase-2). Allelic frequencies of these four loci and those of AGP and PGM (both highly variable and potentially valuable for stock identification) are given in Table 1.

The most obvious differences in gene frequencies occur among large geographic groups of samples. The data suggest the existence of at least three major stock groups. 6PG separates a Gulf stock from the Washington-Oregon (WA-OR) stock group, while ADH, PGI-2, and AGP separate a subgroup in the Gulf of Alaska from the other Gulf samples and from the Washington-Oregon samples.

Variants of 6PG occur consistently at low frequencies along the Washington-Oregon coast, but the variant is absent in all Gulf samples except one (23-16). Chi-square heterogeneity tests were performed to test for significant intra-group variation. No significant differences occurred so that frequencies can be pooled yielding:

Stock group	N	Frequency	95% Confidence interval
WA-OR	1,385	0.96	0.95-0.97
Gulf	332	1.00	0.99-1.00

The 95 percent confidence intervals between the two groups do not overlap. A chi-square contingency test between the groups was highly significant (χ^2_{1df} =13.75, P <0.01). These significant differences indicate that there is probably no long-term gene flow between the two stock groups.

Differences in the frequencies of several markers indicate that there is a subdivision of Pacific ocean perch stocks within the Gulf of Alaska. Allele frequencies in hauls 23-56, 23-55, and 23-1,000 suggest the existence of an isolated population located off Prince William Sound in the central Gulf of Alaska, since ADH (66) variants appear at a high frequency in the Prince William Sound area as follows:

Stock group	N	Frequency	95% Confidence interval
Other Gulf	215	0.040	0.021-0.059
Prince William Sound	117	0.103	0.063-0.143

The 95 percent confidence intervals do not overlap when the frequencies are calculated to three significant figures. The differences are further substantiated by a highly significant chi-square contingency test between the two groups (χ^2_{1df} =10.39, P <0.01). Other evidence for the uniqueness of the Prince William Sound hauls exists in the AGP and PGI-2 frequencies. AGP frequencies for the Prince William Sound hauls and other Gulf hauls are given below (heterogeneity was tested before pooling):

Stock group	N	Frequency	95% Confidence interval
Other Gulf	215	0.59	0.54-0.64
Prince William Sound	117	0.42	0.36-0.48

The confidence intervals do not overlap and the chi-square contingency test is highly significant (χ^2_{1df} =10.79, P <0.01). Although not significant by itself, the PGI-2 frequencies provide another piece of evidence for the separation of the Gulf stocks, since the PGI-2 (87) allele occurs only in the three Prince William Sound hauls. The geographic relationships of the stock group separations based on the preceding evidence is shown on Figure 1.

Westrheim (1970, 1973) initially concluded that two stocks of Pacific

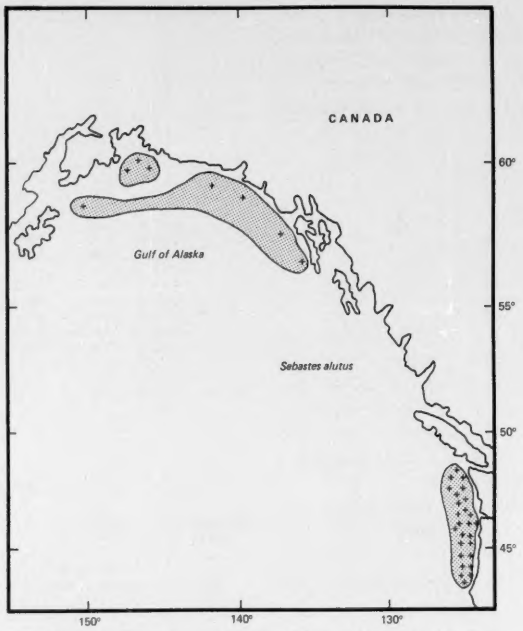

Figure 1.—Sampling localities and stock relationships for Pacific ocean perch based on biochemical genetic data.

ocean perch existed in the northeast Pacific, and tentatively categorized these stocks into British Columbia and Gulf types with the dividing line near Dixon entrance (lat. 54°30'N). These conclusions were based on differential size distributions, year-class strengths, and age-length relationships; he suggested that southeast Gulf fish were more similar to west Gulf fish than to British Columbia fish. However, a different relationship was indicated by more recent data on length-maturity relationships (Westrheim, 1975); i.e., southeast Gulf fish were more similar to British Columbia fish than to west Gulf fish.

The data presented here support the general contention of at least two major stock groups. The two groups identified genetically by 6PG variant frequencies (Washington-Oregon versus Gulf) are presumably analogous to Westrheim's British Columbia and Gulf stocks, although no British Columbia samples were analyzed in this study. These data also strongly indicate the existence of an additional stock group located off Prince William Sound in the central Gulf area that has not previously been identified.

Johnson et al. (1972) observed a nonrandom distribution of PGM phenotypes with depth, where a significantly higher number of heterozygotes (than expected under the Hardy-Weinberg equilibrium) occurred with increasing depths. The data presented here showed no such trend. Chi-square statistics were used to test the observed values against the Hardy-Weinberg expected values, and only one sample out of the 42 collected had a significant deviation from the expected values. No particular PGM phenotype was favored with increasing depth. Preliminary electrophoretic data collected by Henry Tsuyuki (Canadian Department of Environment, Fisheries and Marine Services, Vancouver, B.C., pers. commun. December 1977) also suggested a cline in AGP frequencies with depth off Vancouver Island. When AGP frequencies gathered in this study were plotted against depth, there was no significant correlation ($r^2 = 0.06$). Thus, neither PGM nor APG showed any frequency trends with increasing depth.

The cumulative data support the hypothesis that Pacific ocean perch in the Gulf of Alaska form a series of local populations which only partially intermix (Fadeev, 1968). Fadeev also contended that seasonal migrations are perpendicular to the shelf rather than parallel to it. As the Alaska sampling was only cursory, samples should be gathered and analyzed from all areas of the Gulf of Alaska, including the western Gulf region, the Dixon Entrance area, and the British Columbia coast. More samples are needed in the Prince William Sound region to accurately delineate the boundaries between stocks.

Canary Rockfish

This report provides the first published record of protein polymorphisms for canary rockfish (Table 2). A. G. Johnson (NMFS, Port Aransas, Tex.) recorded a PGM polymorphism in an unpublished report[2]; this polymorphism was substantiated in this study. PGI-2 appeared polymorphic with a total of four alleles at that locus. ME-1 was also moderately polymorphic. Other low frequency variants occurred at the TO, SDH, IDH-1, and ME-2 loci. Overall, canary rockfish had relatively few variants and no high frequency variants. The heterozygosity value (0.022) is low relative to other vertebrates.

The genetic data of different hauls were quite similar and no clear stock separations were apparent such as those observed in Pacific ocean perch. There were, however, two suggestions of situations with possible reduced gene flow. The hauls from strata 6-8 (northern California, lat. 40°25'-44°08'N) completely lacked the variant PGI-2(79). This variant occured in low frequency in strata 9, 11, and 12 (lat. 44°08'-45°00' and 45°50'-47°30'N). Only one sample was taken from stratum 10 (lat. 45°00'-45°50'N), and no variants were observed. No variants were observed in the two hauls from stratum 13 (lat. 47°30'-48°26'N). If strata 6-8 are compared with 9-13 by a contingency test, a chi-square value of 3.2 is generated which is significant at the $P = 0.10$ level.

Some isolation may also exist between the deep and shallow samples based on apparent differences of frequencies of PGM (100). An example occurs in stratum 12. Haul 23-120 has a frequency of 0.78 (95% confidence interval = 0.68-0.85) and was collected at a depth of 44 fathoms. Haul 4-243 has a frequency of 0.95 (0.98-0.87) and was from a depth of 110 fathoms. These confidence intervals do not overlap, suggesting a significant reduction in gene flow.

These two trends are suggestive of some structuring of populations (Fig. 2), but both are inconclusive without further sampling. More samples need to be collected from the deep and shallow extremes within strata, and from specific regions between strata.

Yellowtail Rockfish

No polymorphisms have been previously reported in the literature for yellowtail rockfish. One highly polymorphic system (6PG with five alleles) and one moderately polymorphic system (peptidase) were observed. Low frequency variants were found at PGI-2, MDH-1, IDH-1, and IDH-2 (Table 3). The average heterozygosity for yellowtail rockfish was 0.040.

Data are consistently similar among strata. The one possible exception is haul 4-239 which was the only collection in the deeper ranges (129 fathoms) and possessed a unique allele expressed at a low frequency at the PGI-2 locus. Yellowtail rockfish must be regarded as one homogeneous group within the sampling area without further sampling; this relationship is graphically illustrated in Figure 3.

Bocaccio

Bocaccio had two highly polymorphic loci (PGI-1 and ADH) and an average heterozygosity of 0.056. The data for these and three low frequency variants are given in Table 4.

[2]A. G. Johnson. 1975. Additional data on the biochemical classification of fishes of the family Scorpaenidae. Unpubl. manuscr., 11 p. Panama City Laboratory, NMFS, NOAA, 3500 Delwood Beach Road, Panama City, FL 32401.

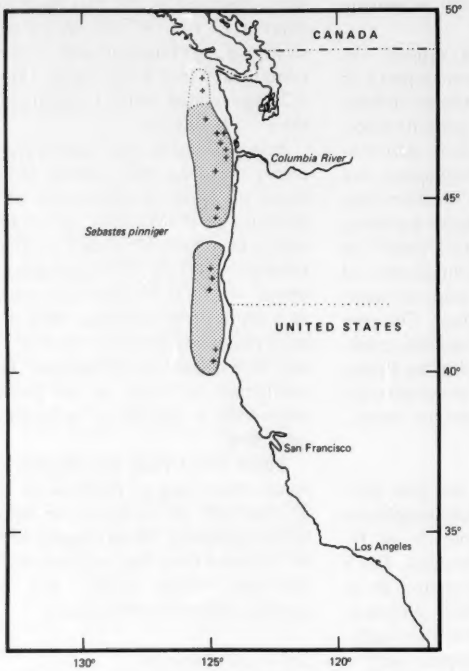

Figure 2.—Sampling localities and possible stock relationships for canary rockfish based on biochemical genetic data.

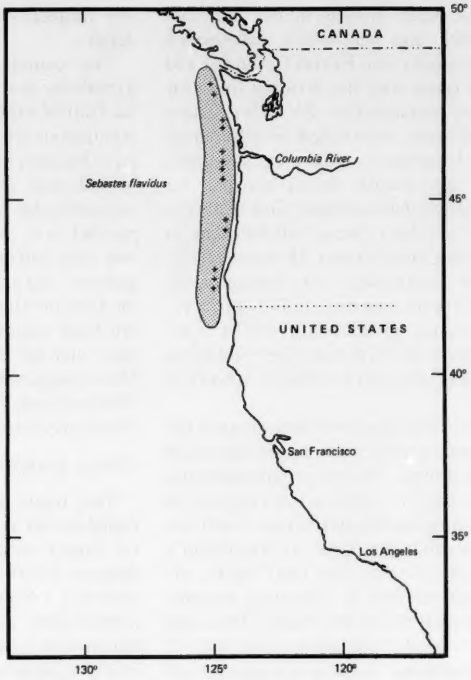

Figure 3.—Sampling localities and stock relationships for yellowtail rockfish based on biochemical genetic data.

The data strongly suggest no genetic differentiation between samples. The samples range over a wide geographic area (strata 1-7, lat. 34°09′-43°00′N), but the alleles have consistently overlapping confidence intervals. The data are especially convincing since the species is so highly polymorphic at two loci. One would not expect these polymorphic loci to remain statistically identical without some gene flow between areas. The sampling areas (and stock relationships) are shown in Figure 4.

Chilipepper

This species is unique for the very low levels of variation associated with it, as reflected in the 0.004 heterozygosity value. This level of variation is unusual, especially in a species with large populations and no barricades to migration. Low frequency variants appeared consistently only at 6PG with an average frequency of 0.02 (Table 5). Rare variants occurred at PGM and PGI-2. All other systems were monomorphic. Sampling localities are shown in Figure 5.

Given the low amount of variation, it is not surprising that no population subdivision was found. Other stock separation techniques may show local differentiation and prove more effective than electrophoresis for this species.

Species Relationships

The five species of rockfish can be compared genetically in terms of their relative genetic similarity to each other. Several indices have been developed for genetic similarity and nearly all of them range from 0 to 1. A similarity of 0 is generated when no alleles are shared in common, while a similarity of 1 indicates that all alleles are not only identical but occur at identical frequencies. Typically populations of one species will show similarities ranging from 0.90 to 1.00; species in the same genus will have similarities ranging downward from 0.90. Rogers' (1972) similarity index was used in this study, and a matrix of the values obtained is given below:

	1.	2.	3.	4.	5.
1. Pacific ocean perch	1.000				
2. Canary rockfish	0.565	1.000			
3. Yellow-tail rockfish	0.566	0.755	1.000		
4. Bocaccio	0.353	0.695	0.712	1.000	
5. Chili-pepper	0.567	0.928	0.847	0.846	1.000

The similarity values can be visualized in a dendrogram generated from standard numerical taxonomic techniques (Sneath and Sokal, 1973) (Fig. 6).

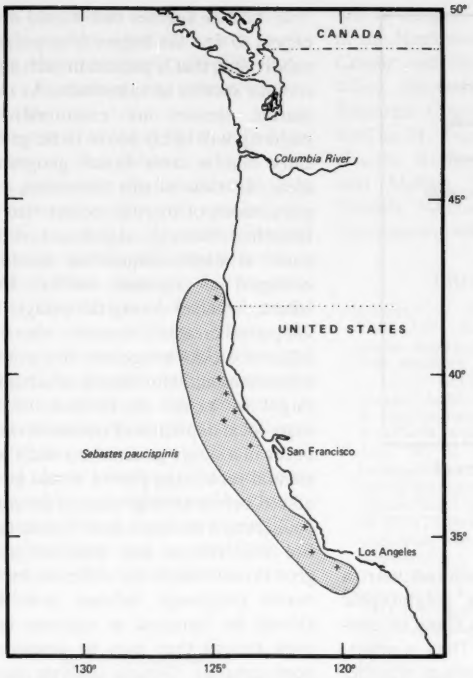

Figure 4.—Sampling localities and stock relationships for bocaccio based on biochemical genetic data.

Figure 5.—Sampling localities and stock relationships for chilipepper rockfish based on biochemical genetic data.

As can be seen from the dendrogram and similarity values, canary rockfish and chilipepper are genetically the closest, clustering at 0.93. This is a very close relationship for nonsibling species. Yellowtail rockfish and bocaccio join in at the 0.81 and 0.75 levels, respectively. Pacific ocean perch is the most distinct lineage joining the other species at the 0.51 level.

The amount of variation associated with a particular species may reveal information concerning the relative age and population structuring of that species. The best measure of the amount of variation found within a species is the average genetic heterozygosity ($\bar{H}$), which represents the average proportion of the genome heterozygous per individual. As mentioned previously vertebrates in general range from 0 to 10 percent with an average of about 6 percent heterozygosity. The values for the five rockfish species are:

Species	$(\bar{H})$
Pacific ocean perch	0.060
Canary rockfish	0.022
Yellowtail rockfish	0.040
Bocaccio	0.056
Chilipepper	0.004

Pacific ocean perch and bocaccio have the highest amount of variation, but both fall in the normal range as compared with other vertebrate species. Chilipepper is especially notable for its low heterozygosity value.

Explaining the amount of variation in a species has been and continues to be a major difficulty in the field of population genetics. However, the data from such diverse organisms as man and salmonids support the theory that the variation can best be explained by random processes (Allendorf and Utter, 1979). This theory holds that the amount of variation is dependent on: 1) the effective population size of the species (based on the number of breeding males and females); 2) the age of the lineage since the population was at a low level of abundance; and 3) the dispersal ability of the species (Soule, 1976). It is reasonable to assume that effective population sizes, although very difficult to quantify, are relatively large in most marine species. Small effective population sizes are characteristic of isolated populations such as island dwellers or populations with very skewed sex ratios and low numbers. The age of the lineage from the last severe reduction in numbers provides the most plausible explanation for the differing amounts of variation in rockfish. By this theory the species with the largest population sizes and the oldest lineage will have the highest amount of variation.

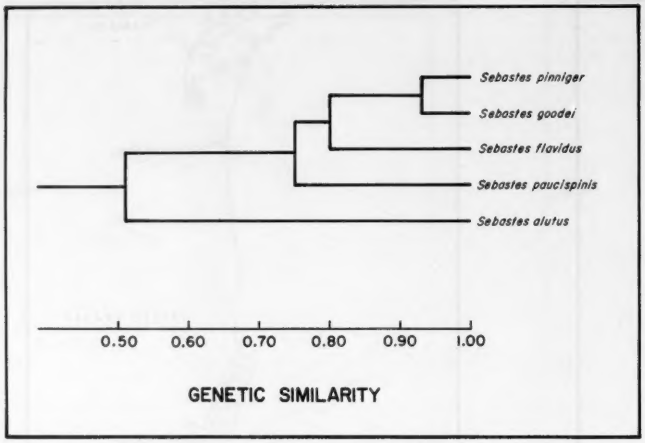

Figure 6.—Dendrogram of genetic similarities for five species of rockfish.

Although only speculative, the data presented here, therefore, suggest that chilipepper possesses the youngest lineage of the five rockfish species and may have passed through small population sizes in the recent past (in terms of evolutionary time). Canary rockfish and chilipepper are genetically quite similar and both have low levels of heterozygosity. It is possible that they have recently diverged from a common ancestor. On the other extreme, both bocaccio and Pacific ocean perch seem to be older lineages with large population sizes. As more data are accumulated on other rockfish species, the evolutionary history of the genus *Sebastes* should become clearer.

Applicability of Electrophoresis To Marine Fisheries

The effectiveness of biochemical genetic techniques as stock separation tools will vary with the species being investigated and the geographic extent of the sampling area. Generally the more variation that exists in the species, the greater the probability will be of finding systems that discriminate between subgroups of the species. However, exceptions do exist. Just one polymorphism with appropriate discriminating frequencies may be sufficient to adequately identify noninterbreeding groups or, alternatively, a species may be highly polymorphic throughout its range but show no geographic differentiation. Thus, a priori, there is no way to determine whether one species will show local differentiation or be genetically homogenous throughout the sampling range, and each species must be screened independently to determine its population structure.

Genetic differences between groups of one species are dependent on the amount of gene flow between these groups. High amounts of gene flow lead to reduced genetic differentiation. Large spawning aggregations and pelagic larvae, characteristic of many marine fishes, both contribute to high degrees of gene flow. Long migrations of individual fish may or may not contribute to high degrees of gene flow, depending on whether the migrants successfully spawn in the new areas or return to their area of origin to spawn. In marine species, such as rockfish, genetic differentiation can occur when groups consistently spawn at different areas or at different times and when the offspring of these fish return to spawn at the same time or place as their parents. Currents or gyres can act to isolate pelagic larvae and create geographic differentiation.

In marine species one would never expect to find the degree of population subdivision that is present in such anadromous species as salmonids. As more marine species are examined, the majority will likely prove to be genetically similar over broad geographic areas. In view of this limitation, subpopulations of marine species that are identified through significant differences of allelic frequencies should be managed as separate stocks. Even where dispersal during the pelagic larval period creates a situation where the adjacent stocks are genetically similar, migrations and movements of adult fish might be extremely limited. In this case, local depletion of one stock might occur in a single generation, and a substantial rebuilding period would be required before immigration of juveniles could return the stock to its former size. For this reason any morphological, growth, or fecundity differences between subgroups indicate that they should be managed as separate units even though they may be genetically homogeneous. Genetic analysis should ideally be done in conjunction with other more classical types of stock separation work, since the two approaches may identify different subgroupings of fish.

Adequate sampling in genetic studies of marine fish is a difficult problem. Ideally the sampling area should cover the total range of the species. Samples from extremes of the species ranges can often provide particularly useful comparisons. In this survey, for instance, the species' ranges are much greater than the actual sampling areas. Additionally, the samples in this survey were all collected by bottom trawling so that individuals inhabiting extremely rocky or reef areas were not sampled. Also, no samples were taken at depths of less than 40 fathoms, and no adequate test can be made of genetic differences between inshore and offshore extremes. In future studies different fishing methods may be necessary to sample the inshore component. For several of the species the data were suggestive of population differences with depth or area, but further sampling is necessary to confirm the initial

findings. Once noninterbreeding groups can be identified with confidence, the areas of contact will be especially interesting and important to resample.

Electrophoresis has been applied to a number of other fisheries problems besides population characterization. It is an extremely effective species discrimination tool and can be applied whenever the identification of a fish is in doubt. This capability can be especially important in a speciose group, such as the rockfish, where the taxonomy is not completely clear and many of the discriminating quantitative characters overlap. The potential is great for using electrophoresis in larval identification, since even very small larvae can be identified to species using electrophoresis. Additionally, electrophoresis is being used increasingly as an enforcement tool in identifying unknown or filleted individuals as to species.

Acknowledgments

The assistance of numerous individuals and organizations in this study is gratefully acknowledged. Paul Aebersold (Northwest and Alaska Fisheries Center, NMFS, NOAA, Seattle, Wash.) provided excellent technical assistance. Assistance in the collection of samples was given by personnel of the Northwest and Alaska Fisheries Center and the Polish Government. Miles Alton (Northwest and Alaska Fisheries Center, Seattle, Wash.) as well as H. Tsuyuki and J. Westrheim (Pacific Biological Station, Fisheries and Marine Service, Environment Canada, Nanaimo, B.C.) provided encouragement and useful discussions.

Literature Cited

Allendorf, F. W., N. Mitchell, N. Ryman, and G. Stahl. 1977. Isozyme loci in brown trout (*Salmo trutta* L.): detection and interpretation from population data. Hereditas 86:179-190.

_____, and F. M. Utter. 1979. Population genetics. *In* W. S. Hoar, D. J. Randall, and J. R. Brett (editors), Fish physiology, Vol. VIII, p. 407-454, Acad. Press, Inc., N. Y.

Fadeev, N. S. 1968. O migratsivakh tikhookeanskogo morskogo okunya (Migrations of Pacific ocean perch). Izv. Tikhookean. Naucho-issled. Inst. Rybn. Khoz. Okeanogr. 65:170-177. [In Russ.] (Transl. avail. Environ. Can., Fish. Mar. Serv., Biol. Stn., St. John's, Newfoundland, as Fish. Res. Board Can. Transl. Ser. 1447, 14 p.)

Johnson, A. G., F. M. Utter, and H. O. Hodgins. 1972. Electrophoretic investigation of the family Scorpaenidae. Fish. Bull., U.S. 70:403-413.

Lisovenko, L. A. 1964. Raspredelenie lichinok tikhookeanskogo morskogo okunya *Sebastodes alutus* Gilbert v zalive Alyaska (Distribution of the larvae of rockfish (*Sebastodes alutus* Gilbert) in the Gulf of Alaska). Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 53 (Izv. Tikhookean. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 52):223-231. [In Russ.] (Transl. by Israel Program Sci. Transl., 1968, p. 217-225 in Soviet fisheries investigations in the northeast Pacific, Part 3, avail. Natl. Tech. Inf. Serv., Springfield, Va., as TT 67-51205.)

Lyubimova, T. G. 1965. Osnovnye etapy zhiznennogo tsikla morskogo okunya *Sebastodes alutus* Gilbert v zal. Alyaska (Main stages in the life cycle of the rockfish *Sebastodes alutus* Gilbert in the Gulf of Alaska). Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 58 (Izv. Tikhookean. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 53):95-120. [In Russ.] (Transl. by Israel Program Sci. Transl., 1968, p. 85-111 in Soviet fisheries investigations in the northeast Pacific, Part 4, avail. Natl. Tech. Inf. Serv., Springfield, Va., as TT 67-51206.)

Rogers, J. S. 1972. Measures of genetic similarity and genetic distance. Studies in genetics VII, Univ. Texas Publ. 7213:145-153.

Selander, R. K., and W. E. Johnson. 1973. Genetic variation among vertebrate species. Annu. Rev. Ecol. Syst. 4:75-91.

Sneath, P. H., and R. R. Sokal. 1973. Numerical taxonomy. W. H. Freeman and Co., San Franc., 573 p.

Soule, M. 1976. Allozyme variation: its determinants in space and time. *In* F. J. Ayala (editor), Molecular evolution, p. 60-77. Sinauer Assoc., Inc., Sunderland, Mass.

Utter, F. M., H. O. Hodgins, and F. W. Allendorf. 1974. Biochemical genetic studies of fishes: potentialities and limitations. *In* D. C. Malins and J. R. Sargent (editors), Biochemical and biophysical perspectives in marine biology, Vol. 1, p. 213-238. Acad. Press, Inc., N.Y.

Westrheim, S. J. 1970. Survey of rockfishes, especially Pacific ocean perch, in the northeast Pacific Ocean, 1963-66. J. Fish. Res. Board Can. 27:1781-1809.

_____. 1973. Age determination and growth of Pacific ocean perch (*Sebastes alutus*) in the northeast Pacific Ocean. J. Fish. Res. Board Can. 30:235-247.

_____. 1975. Reproduction, maturation, and identification of larvae of some *Sebastes* (Scorpaenidae) species in the northeast Pacific Ocean. J. Fish. Res. Board Can. 32:2399-2411.

Maturation and Fecundity of Four Species of *Sebastes*

DONALD R. GUNDERSON, PAMELA CALLAHAN, and BERNARD GOINEY

Introduction

The 1977 survey of rockfish resources offered a unique opportunity to carry out studies of the reproductive biology of yellowtail rockfish, *Sebastes flavidus*; canary rockfish, *S. pinniger*; bocaccio, *S. paucispinis*; and chilipepper, *S. goodei*. Because of their commercial importance these species were singled out for intensive study, and detailed information on their size composition, age composition, and abundance were obtained. Studies of the reproductive biology of these four species were also undertaken to examine their fisheries potential in further detail. The primary objective of these studies was the determination of length-maturity and length-fecundity relationships.

Length-maturity relationships have previously been examined for all four species off California (Phillips, 1964), while Westrheim (1975) provided similar information for yellowtail and canary rockfish off Vancouver Island, B.C. Both workers reported their results as estimates of the length at which 50 percent of the specimens examined were mature (l_{50}), rather than discussing the length-maturity relation in general.

Fecundity studies on these species have also been quite limited, with little work being carried out subsequent to the pioneering work by Phillips (1964). Phillips estimated the fecundity of 24 bocaccio, 23 chilipepper, 15 yellowtail, and 10 canary rockfish, which were collected off California. Subsequent to Phillips' report, additional work on fecundity was carried out by MacGregor (1970) who presented data on the number of oocytes and embryos in 13 specimens of bocaccio, and by Snytko and Borets (1972), who determined the fecundity of 16 specimens of yellowtail rockfish and 4 of bocaccio.

The data collected during the 1977 Rockfish Survey substantially increased the information available on the reproductive biology of the four species examined, and the purpose of this paper is to summarize it.

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ABSTRACT—Length-maturity relationships were determined for yellowtail rockfish, Sebastes flavidus; *canary rockfish,* S. pinniger, *chilipepper,* S. goodei, *and bocaccio,* S. paucispinis. *Length-fecundity relationships were determined for all but the latter. Geographic differences in fecundity were examined for canary rockfish and chilipepper; significant differences were found in samples from chilipepper populations that were 93-185 km (50-100 nautical miles) apart. The results obtained in this study were compared with the limited information published previously. The management implications of differences in fecundity are discussed.*

Methods

For each specimen examined for maturity, fork length was recorded to the nearest centimeter, and maturity state was categorized according to the criteria shown in Table 1. The number of individuals examined, by species, sex, date, and geographic region is shown in Table 2.

All species of *Sebastes* are ovoviviparous, with embryo release occurring 1-5 months after mating for those species that have been studied to date. A primary requisite in determining the length-maturity relation is that maturity observations be obtained when the gonad development of mature individuals is readily apparent. For males, this means that maturity observations should be obtained near the mating period, while female observations should be obtained between the time when vitellogenesis begins ("maturing" state) and embryo release is completed. If this is not accomplished, differentiation of sexually mature and immature individuals is imprecise, leading to erroneous conclusions regarding the length-maturity relation.

An examination of the maturity state of adult fish collected during the survey (Table 3) indicates that males of most species were suitable for the determination of the length-maturity relationships, although the bocaccio examined were just beginning active spermatogenesis. All female yellowtail and

Table 1.— Description of the stages used to describe rockfish maturity.

Sex and maturity stage	Description of gonads
Male	
Immature	Testes string-like, translucent or translucent white.
Maturing	Testes large and swollen, somewhat rounded in cross section, white. Sections of fresh testes produce free-flowing sperm.
Copulation	Milt can be expressed by applying pressure on the body. Testes divided into an inner layer of lighter color with sperm in ampullae, and a more transparent outer layer with voided ampullae.
Sexually inactive	Testes ribbon-like, triangular in cross section, brown. Sections of fresh testes do not have free-flowing sperm.
Female	
Immature	Ovary small and translucent or small and yellow.
Maturing	Ovary firm, eggs yellowish and opaque.
Yolk cleared (eggs fertilized)	Ovary not firm, eggs yellowish and translucent.
Ripe (with embryos or larvae)	Ovary not firm, eggs translucent with black dots or visible larvae.
Spent	Ovary large and flaccid with a reddish purple or dark gray color.
Sexually inactive	Ovary firm, gray or pink, some with black blotches.

canary rockfish examined during the survey (August-September) were maturing but only a limited number of suitable maturity observations could be collected during this period. Fortunately, the Washington State Department of Fisheries has been obtaining maturity observations from commercial landings of yellowtail and canary rockfish since 1975 providing a larger volume of data, obtained nearer the spawning period, for length-maturity analysis of these species.

Maturity observations for female chilipepper collected during the survey indicated that the embryo release period encompasses a relatively short period of time and that most of the individuals examined were just beginning to approach it. Female bocaccio, on the other hand, exhibited a wide range of maturity states, indicating either a single, broad spawning period or multiple spawning. Moser (1967) reported multiple spawning for bocaccio off San Diego and Newport Beach, Calif.

Since a large proportion of both male and female bocaccio examined during the survey were inactive, the length-maturity relationships developed for them should be regarded as tentative, and more detailed studies should be undertaken. It is clear from the results in Table 3, however, that such studies should be carried out somewhat later in the year than July-August.

Ovaries were collected from all four species for the determination of fecundity, but it was later concluded that the bocaccio ovaries were unsuitable for this purpose. Information on the date and location of chilipepper, yellowtail, and canary rockfish collections is shown in Table 4.

All ovaries collected were placed in modified Gilson's solution (Bagenal and Braum, 1968) with the 20 g of mercuric chloride being replaced by 20 ml of Formalin[1] after Ito[2]. After about 2 months, ovarian tissue was removed from the eggs and the fluid was changed. By frequently teasing the ovaries apart and shaking the storage jars, the eggs of several specimens were completely separated from the surrounding ovarian tissue and ready for counting within 3 months of collection.

Mature oocytes, that would presumably develop into viable larvae prior to the next spawning season, were differentiated from immature oocytes on the basis of size frequency curves (Fig. 1). These were obtained by selecting ovaries from several adult specimens at random, and subsampling the oocytes with the same technique used to estimate fecundity (described below). Size frequency for the oocytes was then determined by placing the subsample in a Petri dish and systematically measuring those oocytes lying on transect lines drawn on the dish until 300 observations had been recorded. These observations provided the basis for concluding that most bocaccio ovaries collected were not mature enough to allow differentiation of mature and immature oocytes. Only one of the 10 specimens examined for Figure 1 exhibited the distinct mode of large, maturing oocytes that was typical of the other species examined. On the basis of the data in Figure 1, all chilipepper, yellowtail, and canary rockfish oocytes larger than 0.22 mm were counted as mature oocytes.

Fecundity was estimated through

Table 2.—The number of individual fish examined by species, sex, date, and geographic region.

Species and sex	Area (north latitude)	Date	No. of fish
Canary rockfish			
Males	45°32'-47°30'	8/31-9/16/77	199
Females	47°05'-48°10'	1/25/-4/26[1]	186
Yellowtail rockfish			
Males	46°52'-48°16'	9/14-9/21/77	277
Females	46°20'-48°27'	12/7-4/26[1]	509
Chilipepper			
Males	34°27'-40°05'	7/13-8/16/77	485
Females	34°27'-39°29'	7/13-8/9/77	243
Bocaccio			
Males	34°08'-40°05'	7/8-8/17/77	91
Females	34°08'-40°26'	7/8-8/17/77	84

[1]Collected during 1975-78 by the Washington State Department of Fisheries.

Table 3.—Percentage of adult rockfish in each maturity stage, by species, sex, and season.

Species and sampling period	Males				Females					
	Maturing	Copulation	Inactive	Number examined	Maturing	Yolk cleared	Ripe	Spent	Inactive	Number examined
Canary rockfish										
Aug.-Sept.	100	0	0	173	100					21
Jan.-Apr.					14	35	31	10	11	94
Yellowtail rockfish										
Sept.	100	0	0	238	100					85
Dec.-Apr.					54	13	9	5	18	293
Chilipepper										
July-Aug.	85	0	15	346	59	34	0	2	5	147
Bocaccio										
July-Aug.	29	0	71	56	14	10	8	16	53	51

Table 4.—Date and location of collections for fecundity studies.

Species	Area (north latitude)	Date	No. of fish
Canary rockfish	40°27'-40°29'	8/13	15
	44°23'-46°23'	8/29-9/8	6
	47°29'-47°30'	9/16	10
	48°00'-48°01'	9/25	25
			56
Yellowtail rockfish	48°04'-48°16'	9/21/-9/24	49
Chilipepper	38°03'-38°06'	8/1	22
	39°00'-39°46'	8/7-8/12	61
			83

[1]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[2]D.H. Ito. 1977. Fecundity of the copper rockfish, *Sebastes caurinus* (Richardson), from Puget Sound, Washington. Unpubl. manuscr., 8 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

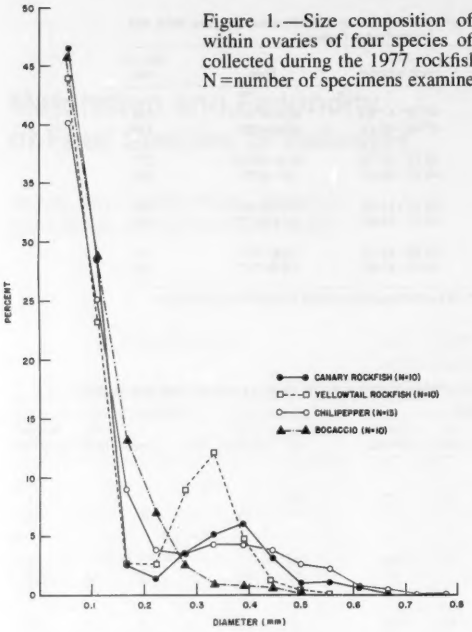

Figure 1.—Size composition of oocytes within ovaries of four species of rockfish collected during the 1977 rockfish survey. N =number of specimens examined.

subsampling by volume. The ovarian contents from each fish were removed from the storage solution, screened to remove large particles of ovarian tissue that remained, and placed in a large beaker. Water was then added until 2,000 ml of oocytes and water had been obtained. The mixture was stirred magnetically until all oocytes were distributed throughout the water column and a 1-5 ml subsample withdrawn with a pipette. Three to six subsamples were taken in this manner, the exact number depending on the standard deviation of the first three subsamples.

The oocytes in each subsample were counted twice (usually by different observers) using a binocular microscope. The mean number of eggs per milliliter was calculated for each of the 3-6 subsample means, and the coefficient of variation (CV = standard deviation /mean of subsample counts) for these subsample means had the following distribution:

CV (%)	Canary rockfish	Yellowtail rockfish	Chili-pepper
0-5.4	62%	78%	69%
5.5-11.4	38	22	31
Total	100%	100%	100%

For most specimens the standard deviation of the subsample means was within 5 percent of the grand mean, regardless of which species was involved. The fecundity of each specimen was estimated from the formula: $F = 2{,}000\ n$, where F = fecundity and n =mean number of eggs per milliliter in the subsamples.

Results

Because of the limited number of maturity observations available, no attempt was made to examine geographic trends in the length-maturity relationship. Instead, the data available for each species were pooled and a single length-maturity relationship determined for each sex.

The length-maturity data (Fig. 2) seemed to conform to a logistic model of the form:

$$P_x = \frac{1}{1 + e^{ax+b}}$$

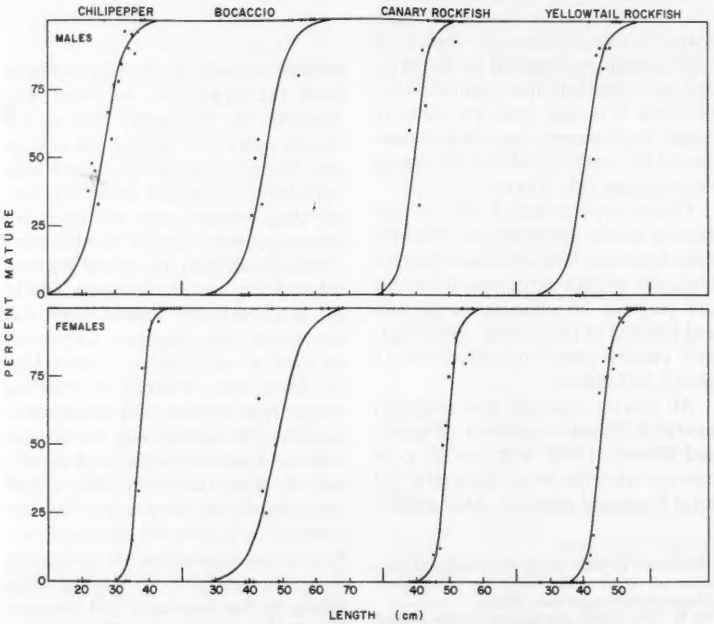

Figure 2.—Proportion of sexually mature fish within each size group, together with the predicted proportion mature (line), by sex and species. Points based on less than three observations were not plotted.

where P_x = proportion mature at length x, and a and b are constants. Maxium likelihood estimates of a and b were obtained and are shown in Table 5. The predicted length[3] at 50 percent maturity ($l_{.50}$) and 95 percent confidence limits around these estimates are also presented in this table.

Only those specimens of chilipepper larger than 37 cm, yellowtail rockfish larger than 43 cm, and canary rockfish larger than 48 cm were used in determining the length-fecundity relation so as to minimize the possibility of including immature individuals in the collections. Differentiation of mature individuals that will spawn next season becomes difficult below these sizes, and the mean fecundity of adult fish could easily be underestimated.

The length-fecundity relationships for chilipepper, canary rockfish, and yellowtail rockfish (Fig. 3-5) all seemed to conform to a linear model: $F = a + bL$, where F = fecundity, a and b are constants, and L = fork length in centimeters.

Length-fecundity relationships for fish are usually curvilinear ($F = aL^b$), and the linear relationship obtained in this study probably resulted from the practice of truncating the analysis near the size at 50 percent maturity. Even those individuals that appeared to be immature contained oocytes that were large enough to be included in the fecundity counts, however, even though there was little likelihood that these fish would mate and develop a brood of embryos. It was concluded that truncating the data at the size where

[3]APL computer program available from Russell Kappenman, Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Table 5.—Maximum likelihood estimates for the parameters of the logistic equation relating proportion mature to length. Predicted length at 50 percent maturity ($l_{.50}$) and 95 percent confidence limits for $l_{.50}$ are also presented.

Species and sex	$\hat{a}$	$\hat{b}$	$l_{.50}$ (cm)	95% confidence interval for $l_{.50}$
Canary rockfish				
Males	−0.4694	18.5360	39.5	(37.9, 41.1)
Females	−0.6171	30.3776	49.2	(48.4, 50.0)
Yellowtail rockfish				
Males	−0.3684	14.9884	40.7	(38.8, 42.6)
Females	−0.5315	23.9411	45.0	(44.5, 45.6)
Chilipepper				
Males	−0.3028	7.8943	26.1	(25.1, 27.0)
Females	−0.6982	25.8478	37.0	(36.3, 37.8)
Bocaccio				
Males	−0.2962	13.2798	44.8	(42.8, 46.9)
Females	−0.2527	12.1677	48.2	(45.4, 50.9)

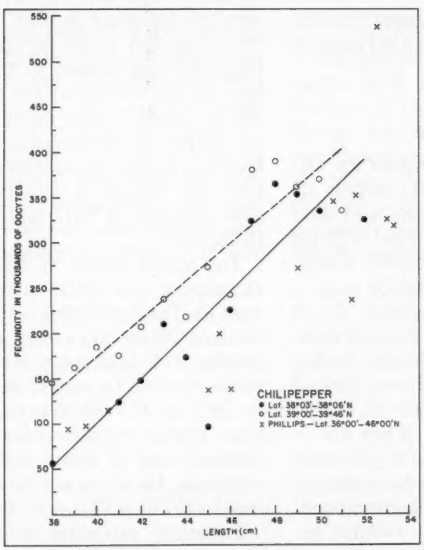

Figure 3.—Predicted relationship between fecundity and length for chilipepper, by geographic region (solid line = southern region, dashed line=northern region). Mean fecundity at each length from the original data and from Phillips' (1964) data is also shown.

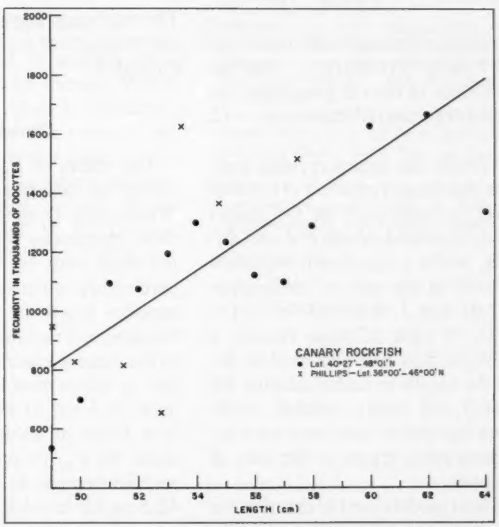

Figure 4.—Predicted relationship between fecundity and length for canary rockfish (line). Mean fecundity at each length from the original data and from Phillips' (1964) data is also shown.

differentiation of mature and immature individuals becomes difficult was preferable to including questionable data in the analysis.

Separate length-fecundity relationships were determined for canary rockfish from lat. 40°27′-40°29′N (Cape Mendocino, Calif.); lat. 47°29′-47°30′N (Sealion Rock, Wash.); and lat. 48°00′-48°01′N (Carrol Island, Wash.), and for chilipepper from lat. 38°03′-38°06′N (Pt. Reyes, Calif.) and lat. 39°00′-39°46′N (Pt. Arena-Cape Vizcaino, Calif.). For each species, the hypothesis that the data from all geographic regions could be fitted to a common line was then tested.

This was done by determining the residual sums of squares (SS) about the separate lines for each geographic region (full model) and around a single regression line (reduced model) where geographic differences were ignored. The hypothesis could then be tested by computing the test statistic:

$$F = \frac{\text{Reduced } SS - \text{Full } SS}{\text{Reduced df} - \text{Full df}} \div \frac{\text{Full } SS}{\text{Full df}}.$$

The degrees of freedom (df) for the full model $= \Sigma(n_i - 2)$ (where n_i = number of specimens in the ith geographic region) and df for the reduced model $= (\Sigma n_i) - 2$.

The results for canary rockfish indicate no significant reduction in residual variance by employing the full model ($F = 1.57$ with 4,44 df; $P(F \geq 1.57) = 0.2$), while a significant reduction was found in the case of chilipepper ($F = 7.03$ with 2,79 df; $P(F \geq 7.03) = 0.0015$). In light of these results, a single regression line was used to describe the length-fecundity relation for yellowtail and canary rockfish, while separate regression lines were used for each geographic region in the case of chilipepper.

The final models used to describe the length-fecundity relationships for the three species in question were:

Yellowtail rockfish

$F = 82721.8L - 3235161$,

Canary rockfish

$F = 64221.3L - 2330029$, and

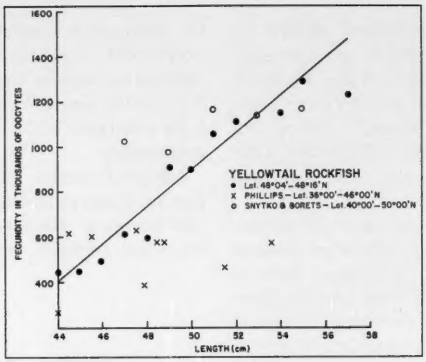

Figure 5.—Predicted relationship between fecundity and length for yellowtail rockfish (line). Mean fecundity at each length from the original data and from the data in Phillips (1964) and Snytko and Borets (1972) is also shown.

Chilipepper

lat. 38°03′-38°06′N

$F = 24297.4L - 870717$

lat. 39°00′-39°46′N

$F = 20809.4L - 658047$.

The regression lines predicted from the above equations are shown in Figures 3 through 5.

Discussion

The values of $l_{.50}$ obtained for yellowtail rockfish and canary rockfish off Washington-Oregon agree well with those reported by Westrheim (1975) for the west coast of Vancouver Island, particularly when the method used to measure length is considered. All of Westrheim's measurements were made to the nearest lower centimeter, so that his $l_{.50}$ values must be adjusted upward about 0.5 cm to compare his results with those in Table 5. When this is done, his $l_{.50}$ estimates for yellowtail rockfish become 40.5 cm for males and 42.5 cm for females, while corresponding estimates for canary rockfish become 41.5 and 48.5, respectively.

Phillips' (1964) results for chilipepper and bocaccio differ widely from those in Table 5, however. Phillips reported that 50 percent of the bocaccio he examined (presumably both sexes) were mature at 41.3 cm total length (TL), far below the values obtained during the rockfish survey (44.8 cm fork length (FL) for males and 48.2 cm FL for females). As pointed out earlier, the bocaccio encountered during the survey were less advanced in their reproductive cycle than would be optimal for length-maturity studies, so that the results for this species are the least reliable presented. Further examination of the length-maturity relationships of bocaccio should be undertaken to resolve the differences between the results obtained in 1977 and those of Phillips.

The results shown in Table 5 for chilipepper also differ substantially from Phillips, and in this case the data obtained during the survey are quite reliable. The discrepancy between $l_{.50}$ values obtained for males (26.1 cm FL vs. 29.2 cm TL) can be explained to a large degree by differences in the methods used to obtain length measurements, but this is not the case with females (37.0 cm FL vs. 30.5 cm TL).

Fecundity estimates obtained by Phillips (1964) and Snytko and Borets (1972) have been plotted in Figures 3-5, to allow direct comparison with the estimates obtained in this study. Phillips measured total length for the specimens in his collection and, if his

observations could readily be converted to fork length, they would all be shifted to the left somewhat. This would enhance the agreement between his results for chilipepper and those found in the current study to some degree, although geographic differences in fecundity could still be responsible for some of the differences indicated in Figure 3. This is particularly true if a substantial fraction of his specimens came from the region south of lat. 38°00'N.

In the case of yellowtail and canary rockfish, the data collected by previous workers are too limited to allow more than a general observation that their estimates are within the range of values found in the current study.

A clear difference in fecundity exists between the species examined in this paper, with yellowtail rockfish and canary rockfish being far more fecund than chilipepper of the same size. A comparison of the fecundity of the five major commercial species of rockfish off the Pacific coast is presented in Table 6.

The length-fecundity relation, size at maturity, and L_∞ information for Pacific ocean perch off Washington and Vancouver Island were obtained from Gunderson (1977), and Phillips' (1964) length-fecundity data were used to obtain a relationship for bocaccio ($F = 0.02997L^{4.1416}$, where L = length in centimeters). Westrheim and Harling's (1975) estimates of L_∞ were used for yellowtail and canary rockfish, and L_∞ for chilipepper and bocaccio were obtained from Wilkins (1980) and Phillips (1964), respectively.

Table 6.—Fecundity (F) at the size at 50 percent maturity and theoretical maximum length (L_∞) for the five species of northeast Pacific rockfish most important to commercial fishermen.

Species	$l_{.50}$ (cm)	F_{50}	L_∞ (cm)	F_∞
Pacific ocean perch	34	30,000	48.5	430,000
Yellowtail rockfish	45	490,000	53.0	1,150,000
Canary rockfish	49	820,000	56.9	1,320,000
Chilipepper	37	70,000	53.2	440,000
Bocaccio	48	280,000	81.3	2,440,000

Table 6 indicates that Pacific ocean perch and chilipepper are characterized by a much lower fecundity than the other species, a difference which must be taken into account when developing management programs for these species. Cushing and Harris (1973) have suggested that fecund species have the greatest capacity for stabilizing their numbers, so that species such as bocaccio, yellowtail rockfish, and canary rockfish should be far more resilient to intensive fishing than Pacific ocean perch or chilipepper.

Acknowledgments

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Literature Cited

Bagenal, T. B., and E. Braum. 1968. Eggs and early life history. *In* W. E. Ricker (editor), IBP Handbook No. 3, Methods for assessment of fish production in fresh waters, p. 159-181. Blackwell Sci. Publ., Oxford.

Cushing, D. H., and J. G. K. Harris. 1973. Stock and recruitment and the problem of density dependence. Rapp. P-V. Réun. Cons. Int. Explor. Mer 164:142-155.

Gunderson, D. R. 1977. Population biology of Pacific ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte Sound region, and their response to fishing. Fish. Bull., U.S. 75:369-403.

MacGregor, J. S. 1970. Fecundity, multiple spawning, and description of the gonads in *Sebastodes*. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 596, 12 p.

Moser, H. G. 1967. Reproduction and development of *Sebastodes paucispinis* and comparison with other rockfishes off southern California. Copeia 1967:773-797.

Phillips, J. B. 1964. Life history studies on ten species of rockfish (genus *Sebastodes*). Calif. Dep. Fish Game, Fish Bull. 126, 70 p.

Snytko, V. A., and L. A. Borets. 1972. Nekotorye dannye o plodovistosti morskikh okunei Vankuvero-Oregonskogo raiona (Some data on fecundity of Pacific ocean perch in the Vancouver-Oregon region). Izv. Tikhookean. Nauchno-issled. Inst. Rybn. Khoz. Okeanogr. 81:249-252. [In Russ.] (Transl. avail. Environ. Can., Fish. Mar. Serv., Pac. Biol. Stn., Nanaimo, B.C., as Fish. Res. Board Can. Transl. Ser. 2502, 5 p.)

Westrheim, S. J. 1975. Reproduction, maturation, and identification of larvae of some *Sebastes* (Scorpaenidae) species in the northeast Pacific Ocean. J. Fish. Res. Board Can. 32:2399-2411.

_____, and W. R. Harling. 1975. Age-length relationships for 26 scorpaenids in the northeast Pacific Ocean. Environ. Can., Fish. Mar. Serv., Tech. Rep. 565, 12 p.

Wilkins, M. E. 1980. Size composition, age composition, and growth of chilipepper, *Sebastes goodei*, and bocaccio, *S. paucispinis*, from the 1977 rockfish survey. Mar. Fish. Rev. 42(3-4):48-53.

Morphology and Distribution Patterns of Several Important Species of Rockfish (Genus *Sebastes*)

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ABSTRACT—This paper investigates some aspects of the relationship between morphology and distribution of some of the commercially important species of rockfish (genus Sebastes*). On the basis of morphometrics, several species pairs of rockfish are suggested. Members of the species pairs are found to be spatially segregated. It is suggested that certain types of adaptive strategies are very important in terms of species that can support commercial fisheries.*

Introduction

In central California, commercial catches of rockfish (genus *Sebastes*) are dominated by bocaccio, *Sebastes paucispinis*, and chilipepper, *S. goodei*. As one moves northward, composition of the commercial catch gradually changes, and in northern Washington, the catch is dominated by Pacific ocean perch, *S. alutus;* silvergray rockfish, *S. brevispinis;* yellowtail rockfish, *S. flavidus;* and canary rockfish, *S. pinniger*. Because of the possibility of a fishery for smaller rockfish species, shortbelly rockfish, *S. jordani*, can also be included in this north-south grouping of commercial species (Table 1).

Table 1.—Commercial rockfish species.

Southern species	Northern species
Chilipepper	Pacific ocean perch
Bocaccio	Silvergray rockfish
Shortbelly rockfish	Yellowtail rockfish
—	Canary rockfish

Several of these commercially important species are very similar in appearance, particularly the Pacific ocean perch and chilipepper and the silvergray rockfish and bocaccio. This similarity in appearance is significant since studies on habitat utilization of fishes with similar feeding morphologies suggest that spatial segregation is probably one of the most important means of niche separation (Werner and Hall, 1977). It is also important because similarity in feeding morphology suggests a similarity in the basic adaptive strategy of these species.

Morphological Relationships

Morphological measurements for these species were taken from Phillips (1957). Variables were chosen which were characteristic of a species' basic adaptive strategy. They include length of head, length of upper jaw, orbit diameter, least depth of caudal peduncle (all as ratios to standard length), the ratio of body height/body width, both at pectoral fins, and maximum recorded length (Table 2).

The first three variables will strongly affect a species' feeding behavior. A species' height/width ratio and depth of caudal peduncle are measures of the hydrodynamic qualities of a fish. The fusiform body, moderately elliptical in cross section, is physically the most efficient for movement through a liquid medium, and therefore is characteristic of species that swim more or less continuously. Species that are in constant motion are also characterized by a narrow caudal peduncle and deeply incised caudal fin (Alexander, 1967). Maximum length was included both because of its effect on movement and because of the effect of absolute size on predation dynamics (Wilson, 1975). The species were clustered using a phi-squared distance coefficient (Sneath and Sokal, 1973). The dendrogram (Fig. 1) shows that species are grouped into a number of species pairs.

Silvergray rockfish and bocaccio are relatively large fish with a large head size and a large jaw size. They also have, relative to the other species, a much smaller orbit. Their body shapes are compressed fusiform and they have moderately incised caudal fins. Bocaccio is primarily piscivorous (Phillips, 1964), and the morphologies of these two species are strongly adapted for

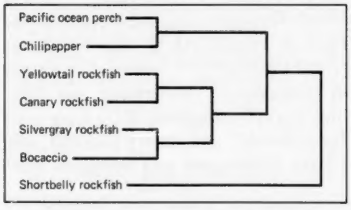

Figure 1.—Cluster analysis of morphological similarity of rockfish species.

Table 2.—Morphological variables for rockfish species (genus *Sebastes*).

Species	Length of head[1]	Length of upper jaw[1]	Orbit diameter[1]	Height/Width	Least depth of caudal peduncle[1]	Maximum length (cm)
Pacific ocean perch	0.370	0.169	0.103	1.97	0.086	50.4
Silvergray rockfish	0.370	0.189	0.090	2.00	0.090	71.1
Yellowtail rockfish	0.357	0.167	0.089	1.67	0.108	66.0
Chilipepper	0.357	0.159	0.085	1.97	0.084	55.9
Shortbelly rockfish	0.344	0.139	0.088	1.88	0.078	30.5
Bocaccio	0.370	0.200	0.074	2.00	0.086	91.1
Canary rockfish	0.357	0.178	0.091	1.97	0.114	76.4

[1]Ratio to standard length.

taking large mobile prey. The large body and mouth size are obvious adaptations for increased prey size. The smaller orbit diameter suggests a reduction in the importance of visual recognition. The large mouth also increases the angle at which a prey item can be taken by allowing the fish to grasp the prey at the side of its jaw (Alexander, 1967). In this way the fish does not have to be directly in front of a prey item for capture. The compressed fusiform body shape and the moderately incised caudal fin suggest an increase in acceleration at the cost of some efficiency in swimming. All of these characteristics show a high level of adaptation for the capture of large mobile prey items.

Pacific ocean perch and chilipepper are smaller fish with smaller mouth sizes. However, their orbit diameter, particularly Pacific ocean perch, is larger. Their body shape is also a compressed fusiform one, but with a more deeply incised caudal fin. These species feed primarily on pelagic crustaceans, particularly on euphausids (Phillips, 1964; Skalkin, 1964). The reduced mouth size is a reflection of the smaller prey size. It also reduces the angle at which the fish can take a prey. The more deeply incised caudal fin suggest a fish which is more efficient at cruising with some sacrifice in acceleration. The increased orbit diameter could imply that a smaller prey size increases the difficulty of visual recognition.

The shortbelly rockfish is the smallest of the species with by far the smallest mouth size. The body shape is a more rounded fusiform one with the smallest height/width ratio. The species also has the narrowest caudal peduncle and is the only species with a deeply incised caudal fin. The shortbelly rockfish feeds primarily on macroplankton (Phillips, 1964). The small mouth size is accompanied by a large orbit diameter. This suggests that prey items are small and even more difficult to see. The body shape is the most strongly adapted for efficient cruising. The shortbelly rockfish has no direct replacement as the other species pairs.

Yellowtail and canary rockfish were paired together primarily because they both have a much thicker caudal peduncle than the other species. However, they are not really similar species except for the fact that they are very different than the other species so far discussed. Also both of these species are members of the northern group of commercial species and have no apparent replacement in the southern group of commercially important species. Since these species represent a fundamentally different line of adaptive strategies, they will not be discussed further.

These species, except for yellowtail and canary rockfish, represent a morphological trend from a large fish with a larger mouth size to a small fish with a smaller mouth size. It is probable that the species also represent to some degree a trend in feeding types. The interesting point is the degree of apparent replacement of species in the transition from the southern to the northern complex.

Distributional Analysis

The similarity of the morphometrics of these species pairs implies that they should show some degree of spatial segregation (Werner and Hall, 1977). The data for this analysis came from the 1977 Rockfish Survey (Gunderson and Sample, 1980). Species densities (in pounds per nautical miles trawled) were calculated in 30-minute blocks of latitude. The data, by species, are shown in Table 3. Histograms were also constructed for the major species for densities combined over all depths (Fig. 2,3).

Association between species was measured from presence-absence data using the binary correlation coefficient, V. Sampling properties and test of significance are given in Pielou (1969). Table 4 gives values of V and their significance.

The histograms of Pacific ocean perch and chilipepper show a trend of a peak of abundance of the southern species, an area of overlap with reduced abundance of both species, and then a peak of abundance in the northern species. The correlation analysis between the species pair shows a strong negative association. The histograms of bocaccio and silvergray rockfish show an area of abundance of the southern species and an area of overlap. The correlation analysis shows a nonsignificant result. This probably is the result of using a presence-absence correlation technique. Use of the abundance

Table 3.—Rockfish species density (pounds per nautical mile) per 30-minute block.

Latitude		Pacific ocean perch	Silvergray rockfish	Yellowtail rockfish	Chili-pepper	Shortbelly rockfish	Bocaccio	Canary rockfish
Deg.	Min.							
34	0	0	0	0	1.7	4.4	5.6	0.3
	30	0	0	0.1	5.5	13.4	23.6	1.0
35	0	0	0	0	0.5	4.9	5.0	0
	30	0	0	0	20.2	31.0	3.2	0.1
36	0	0	0	26.4	0.1	7.4	28.6	0.2
	30	0	0	0	13.1	435.2	15.2	0.8
37	0	0	0	0	15.4	487.1	15.3	0.2
	30	0	0	0	118.5	0.9	269.2	11.9
38	0	0	0	0	99.6	55.0	14.4	0.3
	30	0	0	2.9	53.7	9.5	13.1	1.1
39	0	0.2	0	0.5	92.3	14.4	8.4	0.7
	30	0.1	0	4.2	78.7	1.2	7.6	1.0
40	0	0	0	0	10.7	0.1	1.8	21.5
	30	6.8	0	0	4.6	0	0.5	0
41	0	0.7	0	0.2	0	0	0	0.2
	30	1.1	0	0	0	0	0	0.4
42	0	2.6	0	0.3	0	0	0	0
	30	21.1	0	25.0	0.1	0	1.2	0.8
43	0	6.3	0	1.9	0	0	0.7	5.9
	30	10.9	0	2.2	0	0.1	0.8	0.3
44	0	15.5	1.0	0.2	0	0.7	2.6	3.8
	30	8.8	0	24.6	0	0	0.9	0.1
45	0	13.9	0.2	0.2	0	0	0.2	0.2
	30	23.9	0.3	1.5	0	0.1	1.6	28.8
46	0	101.6	8.6	75.6	0	0	17.9	48.8
	30	133.3	0	80.9	0	0	0.7	60.5
47	0	70.6	15.3	115.6	0	0	7.0	22.3
	30	33.5	10.2	26.1	0	0	0.7	1.1
48	0	180.6	193.3	141.1	0	0	22.8	276.9

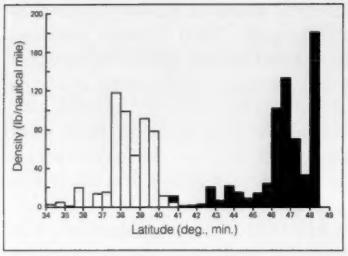

Figure 2.—Pacific ocean perch density (dark bar) and chilipepper density (clear bar) in pounds per nautical mile.

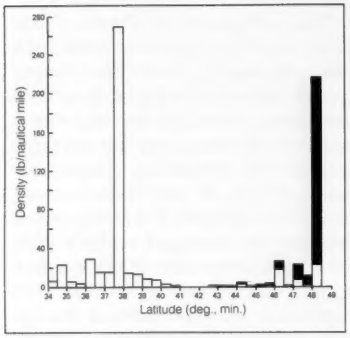

Figure 3.—Silvergray rockfish density (dark bar) and bocaccio density (clear bar) in pounds per nautical mile.

data would have required extensive data editing. However, Figure 3 suggests an inverse relationship between abundances of these two species.

Members of the southern and northern groups of commercially important species appear as distinct entities in the correlation analysis. Members of both the northern and southern groups of species show weak positive association. Between members of the two groups, there is stong negative association.

Table 4.—Binary correlation coefficients for rockfish species.

Species	Pacific ocean perch	Silvergray rockfish	Yellowtail rockfish	Chili-pepper	Shortbelly rockfish	Bocaccio	Canary rockfish
Pacific ocean perch	1.0	.057	−.052	−.316***	−.286***	−.244***	−.095**
Silvergray rockfish	—	1.0	.150***	−.109***	−.101**	.091**	.191***
Yellowtail rockfish	—	—	1.0	−.185***	−.180***	−.013	.289***
Chilipepper	—	—	—	1.0	.045	.022	−.162***
Shortbelly rockfish	—	—	—	—	1.0	.058	−.111***
Bocaccio	—	—	—	—	—	1.0	.065
Canary rockfish	—	—	—	—	—	—	1.0

* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

Discussion

Among the northern and southern groups of commercially important rockfishes, several species can be paired together on the basis of similar morphologies. These species pairs also tend to be spatially segregated. This, in turn, suggests similarities in the basic adaptive strategy of these species pairs. This sort of apparent equivalence between organisms of different regions has long been noted by biogeographers (Levins, 1968).

For a rockfish species to support a commercial fishery, the species must have a large enough body size to provide a marketable fillet, be relatively abundant, and be sufficiently aggregated to provide a profitable catch per unit of effort for the fisherman. Of the approximately 70 species of rockfish off the northeastern Pacific coast, only a few rockfish species have the necessary requirements to support a commercial fishery. The fact that, within the group of commercially exploitable rockfish, certain species show strong similarity in their functional adaptive strategies, points out the importance of these particular adaptive strategies.

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Literature Cited

Alexander, R. McN. 1967. Functional design in fishes. Hutchinson Univ. Libr., Lond., 160 p.

Gunderson, D. R., and T. M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev. 42(3-4):2-16.

Levins, R. 1968. Evolution in changing environments. Some theoretical explorations. Princeton Univ. Press, Princeton, N.J., 120 p.

Phillips, J. B. 1957. A review of the rockfishes of California (family *Scorpaenidae*). Calif. Dep. Fish Game, Fish Bull. 104, 158 p.

_____. 1964. Life history studies on ten species of rockfish (genus *Sebastodes*). Calif. Dep. Fish Game, Fish Bull. 126, 70 p.

Pielou, E. C. 1969. An introduction to mathematical ecology. Wiley-Interscience, N.Y., 286 p.

Skalkin, V. A. 1964. Pitanie morskikh okunei v Beringovous more (Diet of rockfish in the Bering Sea). Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 49 (Izv. Tikhookean. Naucho-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 51):151-166. [In Russ.] (Transl. by Israel Program Sci. Transl., 1968, p. 159-174. *In* Soviet fisheries investigations in the northeastern Pacific, Part 2. Available from Natl. Tech. Inf. Serv., Springfield, Va., as TT 67-51204.)

Sneath, P. H., and R. R. Sokal. 1973. Numerical taxonomy. W. H. Freeman and Co., San Franc., 573 p.

Werner, E. E., and D. J. Hall. 1977. Competition and habitat shift in two sunfishes (Centrarchidae). Ecology 58:869-876.

Wilson, D. S. 1975. The adequacy of body size as a niche difference. Am. Nat. 109:769-784.

Preliminary Analysis of Pacific Coast Demersal Fish Assemblages

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ABSTRACT—The purpose of this portion of an on-going study was to describe demersal fish assemblages on the Oregon continental shelf between the mouth of the Columbia River and Yaquina Head, based on species biomass data collected during the 1977 Rockfish Survey, and to compare these assemblages with those described from data collected in 1973 during the Oregon Department of Fish and Wildlife otter trawl survey. Statistical clustering techniques (including the Bray-Curtis index of dissimilarity and group-average clustering strategy) yielded 12 assemblages. Except for one area (Falcon Shalebeds), species dominating each assemblage were consistent between the two surveys.

Introduction

Using statistical clustering techniques we describe the distribution of northeast Pacific rockfishes and other groundfishes in terms of species assemblages over an area of continental shelf and slope ranging from the mouth of the Columbia River to Yaquina Head off Oregon. Cluster analysis facilitates the description of multispecies distributions.

One benefit of this work is that the catch composition of fleets operating in specific areas can be roughly anticipated from assemblage maps derived from the analysis. Station positions forming the basis of an assemblage monitoring program will be proposed in a later report following analysis of the entire data base covering an area from Point Hueneme, Calif., to Kodiak Island, Alaska.

In this paper, we compare assemblage distributions based on two data sources: The 1973 Oregon Department of Fish and Wildlife (ODFW) otter trawl survey, designed to sample flatfishes; and the portion of the West Coast Joint Agency Rockfish Survey covering a similar area of continental shelf. Whether assemblages persist through a time scale of years is an important fisheries resource question. If assemblages are relatively stable, multispecies management strategies could possibly be devised taking asemblage composition into account.

Cluster Analysis Techniques

Two techniques were used to reduce variability and skewness in the biomass frequency distributions arising from the contagious distribution of many rockfish species. First, data from three adjacent sites, each within a 36.6-m (20-fathom) depth interval parallel to the coast, were pooled or clumped (Tyler and Stephenson[1]) into 55 clumps from 115 sites. Second, data were transformed to $\log_{10}$ values. Clump similarities were described using a Bray-Curtis dissimilarity index (Clifford and Stephenson, 1975). The index for each pair of clumps was calculated from species biomass data expressed as a proportion of the total biomass at each site. A group-average fusion strategy (Clifford and Stephenson, 1975) was used to link similar clumps into clusters. The linked clusters were then displayed in a dendrogram (Fig. 1).

Results of Cluster Analysis

Boundaries were drawn among clumps according to the classifications produced by the clustering algorithm. At a dissimilarity level of 0.50, the dendrogram could be divided into two large clusters or assemblages (Fig. 1). Clumps located at depths greater than 145 m (80 fathoms) were classified apart from those located further inshore (Fig. 1).

At a dissimilarity level of 0.45, three large clusters or assemblages were defined. Of these three, the Intermediate assemblages included clusters A, B, C, and E. They were bounded offshore by the 145-m (80-fathom) contour and inshore by the shallowest site clumps of the survey. The Deep clusters or assemblages included clusters F, G, and H. The component clumps of these clusters were located between the 145-m (80-fathom) and 220-m (120-fathom) contours. The Slope assemblages were comprised of clusters J, L, I, and K. The component clumps of these clusters were located at depths greater than 220 m (120 fathoms). The initial tendency for boundaries to form along depth contours is reinforced by the method of clumping stations within depth intervals parallel to the coast.

Further decomposition of these three main clusters at a dissimilarity level of 0.35 yielded assemblages within each

[1]Tyler, A. V., and W. Stephenson. 1978. Application of statistical cluster analysis methods to otter trawl data. Unpubl. manuscr., 29 p. Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331.

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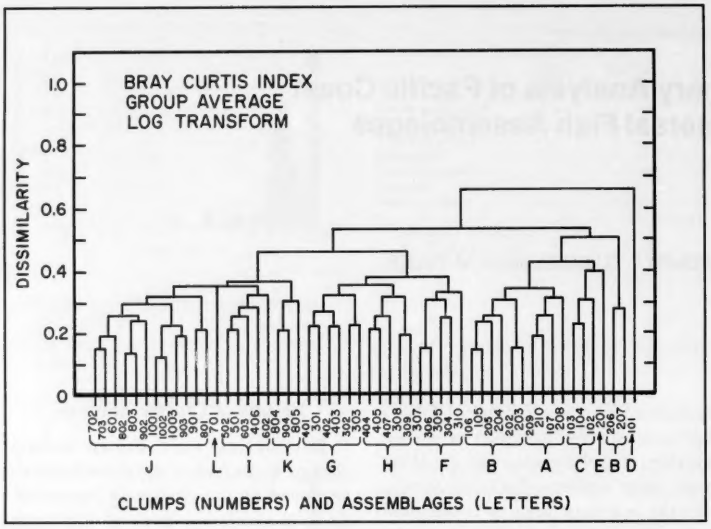

Figure 1.—Classification of site clumps from the Columbia River to Yaquina Head, Oreg., based on 1977 Rockfish Survey data. Numbers refer to site clumps. Letters refer to assemblages: A = Columbia Intermediate, B = Tillamook Intermediate, C = Nestucca Intermediate, F = Falcon Shale, G = Nestucca Deep, H = Tillamook Deep, I = Tillamook Slope, J = Cascade Slope, and K = Columbia Slope. The labels D, E, and L represent only single clumps (3 sites each) not closely linked to any other cluster and are thus not defined as assemblages themselves.

of the depth boundaries. These are shown as lettered clusters in Figure 1 and hatched areas in Figure 2. The use of the 0.35 level of dissimilarity can be justified by the contiguous locations of clumps when cluster divisions are mapped. Assemblage B is labelled in two sections of the dendrogram. The second portion, less closely linked, is comprised of two clumps (206, 207, Fig. 1) in the same geographical region (off Tillamook Head, Fig. 2) as those in the main body of Assemblage B. Species composition within the two clumps was similar to that of the main body. However, catch rates of species other than the dominant species, Pacific whiting, *Merluccius productus,* were so low in this subregion that any higher than average occurrence of a less common species gave the impression of high dissimilarity. Consequently, we decided it would be undue embellishment to classify the clumps as a separate assemblage.

The species composition (by biomass) in each assemblage is listed in Table 1. Infrequently occurring fish taxa which were recorded but not displayed in Table 1 included the Pacific electric ray, *Torpedo californica;* Pacific halibut, *Hippoglossus stenolepis;* slender sole, *Lyopsetta exilis;* northern anchovy, *Engraulis mordax;* American shad, *Alosa sapidissima;* aurora rockfish, *Sebastes aurora;* silvergray rockfish, *S. brevispinis;* rosethorn rockfish, *S. helvomaculatus*; shortbelly rockfish, *S. jordani; Argyropelecus* sp.; *Icelinus* sp.; Agonidae; Chauliodontidae; Myctophidae; Liparidae; and Zoarcidae. We named the assemblages by their correspondent geographical features.

Five species were widely distributed over the Intermediate, Deep, and Slope assemblages: Pacific whiting; sablefish, *Anoplopoma fimbria;* Dover sole, *Microstomus pacificus;* arrowtooth flounder, *Atheresthes stomias;* and rex sole, *Glyptocephalus zachirus.* The Columbia Intermediate, Tillamook Intermediate, and Nestucca Intermediate assemblages (Fig. 2) were all dominated by Pacific whiting, as was the Nestucca Deep assemblage farther offshore. Dover sole dominated the Columbia Slope and Cascade Slope assemblages. These five species were commonly among the six most abundant species ranked by catch weight throughout assemblage strata.

Although Pacific whiting dominated all three Intermediate assemblages, the degree of domination was least in the Columbia Intermediate Assemblage. In that assemblage, Pacific whiting composed 30.1 percent of the biomass caught, at 152.8 pounds/haul, compared with 80.5 percent of the total biomass of both the Tillamook and Nestucca Intermediate assemblages, at 646.4 and 653.3 pounds/haul, respectively. Catch per haul of other species was greater in the Columbia Intermediate Assemblage than in the other two assemblages.

Dover sole, the second most abundant species in the assemblage, composed 20.2 percent of the total biomass with a catch rate of 102.7 pounds/haul. Canary rockfish, *Sebastes pinniger;* arrowtooth flounder; and sablefish were the third to fifth most abundant species, at catch rates of 82.7, 43.8, and 24.2 pounds/haul, respectively. Percentage composition of these species (on a biomass basis) was 16.3, 8.6, and 4.8 percent, respectively. Rex sole were more abundant in this assemblage than any other. These principal species were also important in the Tillamook Intermediate Assemblage as well. There, the second major species (after Pacific whiting) was canary rockfish (9.1 percent of total biomass, 73.4 pounds/haul). However, the third to fifth most abundant species, arrowtooth flounder, Dover sole, and sablefish, respectively, composed less than 3 percent of the total biomass each, and occurred at rates of 14-20 pounds/haul.

The Nestucca Intermediate Assemblage, also heavily dominated by Pacific whiting, was separated from other assemblages by the high occurrences of Pacific herring, *Clupea haren-*

gus pallasi, and eulachon, *Thaleichthys pacificus* (3.9 and 3.5 percent of total biomass, 31.9 and 28.6 pounds/haul, respectively). The assemblage was also characterized by highest relative abundance and catch rate of lingcod, *Ophiodon elongatus,* among all assemblages.

Among Deep assemblages, catch rates were highest in the Falcon Shale Assemblage. Redstripe rockfish, *S. proriger,* was the most abundant species in this assemblage, followed by canary rockfish. These species occurred at higher catch rates (249.5 and 142.5 pounds/haul, respectively) and composed a larger percentage of the catch (28.5 and 16.3 percent, respectively) than in any other assemblage described. Other important species in this assemblage included sablefish, arrowtooth flounder, and Pacific whiting. The first two of these three species occurred at higher catch rates (101.4, 91.8, and 71.0 pounds/haul, respectively) than elsewhere. Yellowtail rockfish, *S. flavidus,* were also relatively important in this assemblage (4.4 percent of biomass, 38.4 pounds/haul).

The Tillamook Deep Assemblage was dominated by two rockfish species as well, sharpchin rockfish, *S. zacentrus,* and Pacific ocean perch, *S. alutus,* both of which occurred there in greater abundance than they did in most of the other assemblages (23.7 and 15.4 percent of total weight caught, 149.3 and 96.9 pounds/haul, respectively). Dover sole, arrowtooth flounder, sablefish, and Pacific whiting were also highly important. Splitnose rockfish, *S. diploproa,* were most common in the Tillamook Deep Assemblage.

The Nestucca Deep Assemblage was the only Deep assemblage not dominated by rockfishes. Pacific whiting and sablefish were most abundant (32.1 and 20.9 percent by biomass, 128.1 and 83.3 pounds/haul, respectively), followed by arrowtooth flounder and Dover sole (12.9 and 6.7 percent, 51.5 and 26.7 pounds/haul, respectively). Pacific ocean perch and darkblotched rockfish, *S. crameri,* were ranked fifth and sixth by weight (6.5 and 3.9 percent, 25.8 and 15.8 pounds/haul, respectively).

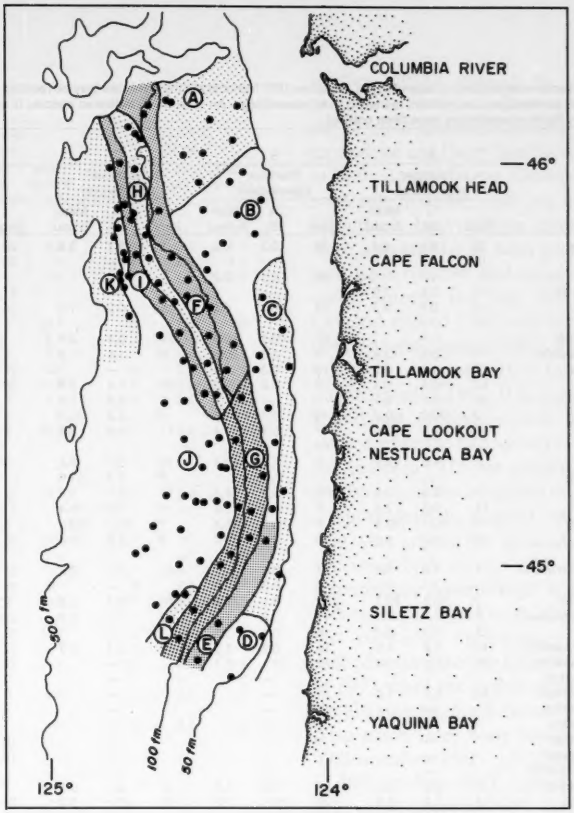

Figure 2.—Map of groundfish assemblages from the Columbia River to Yaquina Head, Oreg., based on component site clumps from 1977 West Coast Joint Agencies Rockfish Survey data. Dots represent trawl sets. Letters refer to assemblages: A = Columbia Intermediate, B = Tillamook Intermediate, C = Nestucca Intermediate, F = Falcon Shale, G = Nestucca Deep, H = Tillamook Deep, I = Tillamook Slope, J = Cascade Slope, and K = Columbia Slope. The labels D, E, and L represent only single clumps (3 sites each) not closely linked to any other cluster and are thus not defined as assemblages themselves.

Compared with other Slope assemblages, the Tillamook Slope was characterized by highest abundances (mean pounds/haul) of Pacific ocean perch and darkblotched rockfish (97.2 and 48.6 pounds/haul, respectively). Percent composition contributed by these species was 33.6 and 16.8 percent, respectively. Dover sole was the third most abundant species in the assemblage (based on percent composition) although the catch rate was lower than in other Slope assemblages. Shortspine thornyhead, *Sebastolobus alascanus,* ranking fourth in the Tillamook Slope Assemblage, occurred at approximately the same relative abundance (percent composition) and catch rate (pounds/haul) as in the Cascade Slope Assemblage. Sablefish and Pacific whiting occurred at levels intermediate to the other two Slope assemblages. Among Slope assemblages, the Tillamook Slope contained highest

Table 1.—Species composition of assemblages, based on 1977 National Marine Fisheries Service rockfish survey. Species listed include those which ranked among the 15 most abundant (by percentage composition, biomass) in an assemblage. An asterisk (*) indicates species is one of six most abundant (by percentage composition, biomass) in an assemblage. Some invertebrates have been omitted.

	A			B			C			F			G			H		
	Columbia Intermediate			Tillamook Intermediate			Nestucca Intermediate			Falcon Shale			Nestucca Deep			Tillamook Deep		
Species	Rank	% (lb)	Mean lb/haul	Rank	% (lb)	Mean lb/haul	Rank	% (lb)	Mean lb/haul	Rank	% (lb)	Mean lb/haul	Rank	% (lb)	Mean lb/haul	Rank	% (lb)	Mean lb/haul
Spiny dogfish	24	0.1	0.6	16	0.2	1.4	9	0.7	5.8	28	0.1	0.9	10	1.4	5.7	28	0.1	0.5
Big skate	13	0.9	4.5		—			—		35	<0.1	0.2	12	1.3	5.2		—	
Black skate		—		28	<0.1	0.2		—			—		31	<0.1	0.1		—	
Longnose skate	17	0.6	2.9		—			—		21	0.3	2.9	32	<0.1	0.1	36	<0.1	0.1
Ratfish	14	0.9	4.3	23	0.1	0.5	15	0.2	1.8	23	0.2	1.5	20	0.3	1.3	25	0.2	1.0
Pacific sanddab		—		27	<0.1	0.2	14	0.3	2.8		—			—			—	
Arrowtooth flounder	4*	8.6	43.8	3*	2.6	20.5	6*	1.4	11.0	4*	10.5	91.8	3*	12.9	51.5	4*	8.6	54.4
Flathead sole	11	1.1	5.5	13	0.3	2.1		—		27	0.4	1.3		—		26	0.1	0.9
Petrale sole	27	<0.1	0.4	19	0.2	1.2	13	0.4	2.8	32	<0.1	0.4	26	0.1	0.4	23	0.2	1.3
English sole	30	<0.1	0.1		—		8	0.9	7.3		—			—		32	<0.1	0.1
Dover sole	2*	20.2	102.7	4*	1.7	13.8	4*	2.6	21.4	8	4.4	38.4	4*	6.7	26.7	3*	10.7	67.3
Rex sole	6*	4.2	21.5	7	0.4	3.4	11	0.6	4.8	9	1.4	12.2	8	2.2	8.6	11	2.2	14.1
Sablefish	5*	4.8	24.2	5*	1.7	13.7	10	0.7	5.4	3*	11.6	101.4	2*	20.9	83.3	5*	7.7	48.5
Pacific herring		—			—		2*	3.9	31.9		—			—			—	
Pacific cod	7	2.6	13.4	14	0.2	1.6	12	0.4	3.2	14	0.8	6.6	15	0.7	2.8	24	0.2	1.0
Lingcod	18	0.5	2.8	8	0.4	3.3	5*	2.0	16.4	17*	0.4	3.4	17	0.4	1.8	21	0.3	2.2
Pacific whiting	1*	30.1	152.8	1*	80.5	646.4	1*	80.5	653.3	5*	8.1	71.0	1*	32.1	128.1	6*	6.4	40.3
Eulachon	10	1.2	6.3	9	0.3	2.7	3*	3.5	28.6	10	1.0	8.6	11	1.4	5.4	33	<0.1	0.1
Shortspine thornyhead	8	1.9	9.6	22	<0.1	0.7	23	<0.1	0.2	13	0.9	7.8	7	3.1	12.4	10	2.8	17.9
Boccaccio		—		11	0.3	2.4		—		16	0.5	4.5	18	0.4	1.5	15	1.0	6.3
Canary rockfish	3*	16.3	82.7	2*	9.1	73.4	20	0.1	0.8	2*	16.3	142.5	28	0.1	0.3	8	4.1	26.0
Darkblotched rockfish	9	1.4	7.1	17	0.2	1.4	17	0.1	0.9	22	0.2	2.1	6*	3.9	15.8	9	3.3	20.9
Flag rockfish	23	0.1	0.6	18	0.1	1.2		—		19	0.4	3.3	32	<0.1	0.1	18	0.5	3.4
Greenstriped rockfish	16	0.8	4.0	15	0.2	1.5	18	0.1	0.9	15	0.6	5.6	13	1.0	3.8	16	0.9	5.6
Pacific ocean perch	28	<0.1	0.4	29	<0.1	0.1		—		24	0.2	2.0	5*	6.5	25.8	2*	15.4	96.9
Redstripe rockfish		—			—			—		1*	28.5	249.5		—		13	1.9	11.9
Rougheye rockfish	19	0.3	1.6		—			—			—		27	0.1	0.4	37	<0.1	0.1
Sharpchin rockfish		—			—			—		6*	5.6	48.8	29	0.1	0.3	1*	23.7	149.3
Splitnose rockfish		—			—			—			—		16	0.6	2.5	7	4.2	26.6
Stripetail rockfish		—			—			—		12	0.9	8.0	14	0.9	3.6	14	1.0	6.4
Yelloweye rockfish		—			—			—		18	0.4	3.4		—		27	0.1	0.8
Yellowmouth rockfish		—			—			—			—			—		12	2.0	12.3
Yellowtail rockfish	5	0.8	4.2	10	0.3	2.5	19	0.1	0.9	7	4.4	38.4	21	0.2	1.0	29	0.1	0.4
Widow rockfish	12	1.0	5.3	23	<0.1	0.2	22	<0.1	0.2	25	0.2	1.9	19	0.3	1.3	20	0.4	2.3
Squid		—			—			—			—			—			—	
Dungeness crab	21	0.3	1.5	6*	0.4	3.5	7	1.2	9.4	36	<0.1	0.2	30	<0.1	0.2		—	

Continued on next page

abundances of splitnose rockfish and the only occurrence of sharpchin rockfish.

The Columbia Slope Assemblage was highly dominated by Dover sole, representing 43.2 percent of the total weight caught, and highest mean catch rate (77.7 pounds/haul) found in any of the Slope assemblages. Of lesser importance were Pacific ocean perch (15.3 percent of total weight, 27.6 pounds/haul); and darkblotched rockfish, sablefish, and Pacific whiting, ranging from 5.6 to 6.8 percent of total catch and from 10.1 to 12.1 pounds/haul. Rex sole and yelloweye rockfish, *Sebastes ruberrimus*, were most abundant in this assemblage, relative to other Slope assemblages.

The three most abundant species in the Cascade Slope Assemblage, Dover sole, Pacific whiting, and sablefish, contributed nearly equal weights to the total catch (18.3, 16.6, and 15.4 percent, respectively) and occurred at nearly equal mean weights/haul (46.9, 42.5, and 39.3 pounds/haul, respectively). Sablefish and Pacific whiting were more abundant here than in the other two Slope assemblages. Rougheye rockfish, *S. aleutianus*, were more abundant in this assemblage than in any other Slope assemblage.

Comparison With 1973 Oregon Survey

Difference in species abundance between the 1973 ODFW survey and the 1977 Rockfish Survey may be due to gear differences. Since the 1973 survey gear was designed to capture flatfishes efficiently, it is not surprising that soles and skates ranked much higher in 1973 than in 1977. The 1977 survey was conducted with a trawl that is more efficient for off-bottom fishes, and so increased catches of the genera *Sebastes*, *Thaleichthys*, and *Clupea* in 1977 cannot be interpreted as a real abundance shift. Differences in catch per haul may also be partially ascribed to differences in sampling programs. Hauls taken by the ODFW covered 1 nautical mile, while hauls taken during the 1977 Rockfish Survey covered an average of 1.5 nautical miles each. However, decreased catch per haul of rockfishes in 1977 relative to 1973 is not likely to be an artifact of sampling procedure.

Table 1.—Continued.

Species	I Tillamook Slope Rank	% (lb)	Mean lb/haul	J Cascade Slope Rank	% (lb)	Mean lb/haul	K Columbia Slope Rank	% (lb)	Mean lb/haul
Spiny dogfish		—			—			—	
Big skate		—			—			—	
Black skate	18	0.1	0.3	20	0.1	0.3	14	0.5	0.9
Longnose skate		—		13	0.7	1.7	9	2.5	4.4
Ratfish	12	0.6	1.9	17	0.2	0.4	11	1.2	2.2
Pacific sanddab		—			—			—	
Arrowtooth flounder	8	3.9	11.2	7	6.3	16.1	12	1.1	2.0
Flathead sole		—			—			—	
Petrale sole		—		28	0.2	0.4		—	
English sole		—		15	0.3	0.7	16	0.2	0.4
Dover sole	3*	10.0	29.0	1*	18.3	46.9	1*	43.2	77.7
Rex sole	11	1.2	3.6	11	1.3	3.4	6*	5.4	9.8
Sablefish	5*	7.5	21.8	3*	15.4	39.3	4*	6.4	11.6
Pacific herring		—			—			—	
Pacific cod		—			—			—	
Lingcod		—			—			—	
Pacific whiting	6*	6.1	17.5	2*	16.6	42.5	5*	5.6	10.1
Eulachon		—			—			—	
Shortspine thornyhead	4*	8.9	25.7	5*	8.4	21.6	7	4.7	8.5
Boccaccio	16	0.2	0.5		—			—	
Canary rockfish		—		24	0.1	0.2		—	
Darkblotched rockfish	2*	16.8	48.6	12	1.2	3.1	3*	6.8	12.1
Flag rockfish	13	0.6	1.7	10	2.2	5.6	17	0.1	0.2
Greenstriped rockfish		—			—			—	
Pacific ocean perch	1*	33.6	97.2	8	5.0	12.8	2*	15.3	27.6
Redstripe rockfish	15	0.2	0.5		—			—	
Rougheye rockfish		—		6*	7.7	19.8	15	0.2	0.4
Sharpchin rockfish	9	2.2	6.4		—			—	
Splitnose rockfish	7	5.6	16.3	9	2.7	6.9	13	0.9	1.6
Stripetail rockfish	19	0.1	0.1		—			—	
Yelloweye rockfish		—			—		8	3.6	6.4
Yellowmouth rockfish	14	0.4	1.3	22	0.1	0.2		—	
Yellowtail rockfish		—			—			—	
Widow rockfish	17	0.1	0.3	25	0.1	0.1		—	
Squid	10	1.8	5.3	16	0.2	0.6		—	
Dungeness crab		—			—			—	

A complete discussion of the 1973 ODFW survey results is not included here because the assemblages have been described elsewhere (Tyler and Stephenson, footnote 1).

Maps of the assemblages (Fig. 2, 3) show similarities between years. For both surveys, assemblages were strongly associated with depth contours. Intermediate depth assemblages lay between the 90- and 145-m contours (50-80 fathoms) in both years (assemblages A, B, C and D, E in Fig. 2 and 3, respectively). No assemblage corresponding to the Columbia Intermediate was found in 1973 and there was a sharper north-south delineation of the Tillamook and Nestucca Intermediate Assemblages that year. The Nestucca Deep Shelf Assemblage (Fig. 2G, Fig. 3H) is in the same geographic position. The Tillamook Deep and Falcon Shale Assemblage (Fig. 2H,F; Fig. 3F,G) vary somewhat between surveys in that the Falcon Shale Assemblage does not extend as far north in the 1973 survey as it did in 1977. Three shallow assemblages occurring in regions shallower than 90 m (50 fathoms) were described from data collected on the 1973 survey. There is no basis for comparison for the inner shelf, unsampled in 1977; and also the slope regions, unsampled in 1973.

In both surveys, the Intermediate Assemblages as well as the Nestucca Deep Assemblage were dominated by Pacific whiting. Substantial catches of Pacific whiting were also made in the Tillamook Deep Assemblage where the species ranked seventh in 1973 and sixth in 1977. Others that were among the 11 most abundant species in all Intermediate and Deep Shelf assemblages in both surveys were: Dover sole, arrowtooth flounder, and rex sole. The Tillamook Intermediate assemblages were also similar in both years in that yellowtail rockfish and canary rockfish were among the top 10 species. Lingcod ranked 14th with a catch rate of 9.6 pounds/haul in 1973, and ranked 8th with a mean catch rate of 3.3 pounds/haul in 1977. It is likely that the abundance of lingcod was about the same during the two surveys. The rank was lower in 1973 due to higher ranking flatfishes and the longnose skate.

Spiny dogfish, lingcod, and English sole were among the 10 most abundant species in both surveys of the Nestucca Intermediate Assemblage. A difference seemed to be that Pacific cod, yellowtail rockfish, and canary rockfish ranked among the top 10 in 1973 but not in 1977 when the higher opening trawl should have captured them more easily. Also catch rates were lower in 1977: Yellowtail rockfish, 15.3 pounds/haul in 1973, 0.9 in 1977; canary rockfish, 5.2 pounds/haul in 1973, 0.8 in 1977; Pacific cod, 6.0 pounds/haul in 1973, 3.2 in 1977.

The Nestucca Deep Assemblages were similar in both years. Spiny dogfish, shortspine thornyhead, Pacific ocean perch, and darkblotched rockfish were among the top 10 species. Three rockfish appeared to be less abundant in 1977 than in 1973: Greenstriped rockfish, *S. elongatus*, ranked 8th in 1973, 24.9 pounds/haul, and ranked 13th in 1977, 3.8 pounds/haul; yellowtail rockfish ranked 14th in 1973, 3.4 pounds/haul, and ranked 21st in 1977, 1.0 pound/haul; stripetail rockfish, *S. saxicola*, ranked 9th in 1973, 13.5 pounds/haul, and ranked 14th in 1977, 3.6 pounds/haul.

The Tillamook Deep Assemblages were similar in both years. Shortspine thornyhead, Pacific ocean perch, and darkblotched rockfish ranked among the 10 most abundant species each year. Less abundant species also showed similarities. Greenstriped rockfish ranked 11th in 1973, with a catch rate of

1.5 pounds/haul, ranked 16th in 1977, catch rate of 5.6 pounds/haul. Lingcod ranked 13th, catch rate of 4.9 pounds/haul in 1973, and ranked 21st, catch rate of 2.2 pounds/haul in 1977.

The Falcon Shale Assemblage was noticeably different in the two surveys. In 1973 catches were poor in both number of species taken and low mean catch rates but this was not true in 1977. The mean catch rate of the 10 most abundant species in 1973 was 17.2 pounds/haul, but 80.3 pounds/haul in 1977. This is partially ascribable to longer duration of tows in 1977. There were 14 species of fish recorded in 1973, and 30 in 1977. Except for the ubiquitous species and canary rockfish, the species composition of the 10 most abundant species was different.

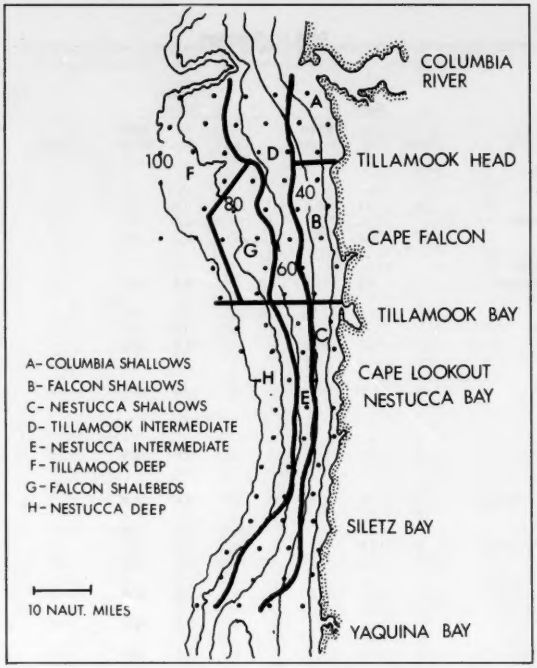

Figure 3.—Map of groundfish assemblages from the Columbia River to Yaquina Bay, Oreg., based on component site clumps from 1977 Oregon Department of Fish and Wildlife otter trawl survey data. Dots represent trawl sets.

Summary and Conclusions

The groundfish fauna on the continental shelf and slope off Oregon, between the Columbia River and Yaquina Head (Newport), consists of four major faunistic zones: The shallow neritic zone, from nearshore to 90 m (50 fathoms); the intermediate shelf zone, 90-145 m (50-80 fathoms); the deep shelf zone, 145-220 m (80-120 fathoms); and the slope zone beginning at 220 m. The analysis of the shallow zones was reported elsewhere (Tyler and Stephenson, footnote 1) from the ODFW survey. Over the four major faunistic zones there were 12 assemblages: The Columbia Shallows, Falcon Shallows, Nestucca Shallows, Columbia Intermediate, Tillamook Intermediate, Nestucca Intermediate, Tillamook Deep, Falcon Shale, Nestucca Deep, Tillamook Slope, Cascade Slope, and Columbia Slope. Since many of the species in these assemblages undergo seasonal movements or migrations, these descriptions are primarily applicable to summer conditions.

The shallow water assemblages are characterized mainly by differences in flatfish presence and abundance. The intermediate shelf assemblages are dominated by Pacific whiting and by species overlapping from the shallow shelf and the deep shelf zones. The deep shelf assemblages are characterized by combinations of rockfish species. Pacific ocean perch, Pacific whiting, arrowtooth flounder, Dover sole, sablefish, and darkblotched rockfish tend to be among the more abundant species throughout the deep shelf and slope zones. The slope assemblages are set apart mainly by combinations of rockfish species. Except for the Falcon Shale Assemblage, species dominance was consistent between 1973 and 1977 surveys.

Acknowledgments

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Literature Cited

Clifford, H. J., and W. Stephenson. 1975. An introduction to numerical classification. Acad. Press, Inc., N.Y., 229 p.

Editorial Guidelines for *Marine Fisheries Review*

Marine Fisheries Review publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under completed NOAA Form 25-700.

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Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

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